AGARD-LS-208

AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT
7 RUE ANCELLE, 92200 NEUILLY-SUR-SEINE, FRANCE

AGARD LECTURE SERIES 208

Injury Prevention in Aircraft Crashes: Investigative Techniques and Applications

(la Prévention des lésions lors des accidents d'avions : les techniques d'investigation et leurs applications)

The material in this publication was assembled to support a Lecture Series under the sponsorship of the Aerospace Medicine Panel and the Consultant and Exchange Programme of AGARD presented on 24-25 November 1997 in Farnborough, UK, and 1-2 December 1997 in Madrid, Spain.

NORTH ATLANTIC TREATY ORGANIZATION

Published February 1998

Distribution and Availability on Back Cover

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North Atlantic Treaty Organization

Organisation du Traité de l'Atlantique Nord

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— Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community;

— Providing scientific and technical advice and assistance to the Military Committee in the field of aerospace research and development (with particular regard to its military application);

— Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;

— Improving the co-operation among member nations in aerospace research and development;

— Exchange of scientific and technical information;

— Providing assistance to member nations for the purpose of increasing their scientific and technical potential;

— Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field.

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* AGARD merged with the Defence Research Group of NATO (DRG) on 1 January 1998 to form the Research and Technology Organization (RTO) of NATO. However, both AGARD and DRG will continue to issue publications under their own names in respect of work performed in 1997.

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Printed on recycled paper

Published February 1998

ISBN 92-836-1068-7

Printed by Canada Communication Group Inc.
(A St. Joseph Corporation Company)
45 Sacré-Cœur Blvd., Hull (Québec), Canada K1A 0S7

Injury Prevention in Aircraft Crashes: Investigative Techniques and Applications

(AGARD LS-208)

Executive Summary

The Aerospace Medical Panel (AMP) of the RTO (former Advisory Group for Aerospace Research and Development - AGARD) organised LS 208 on "Injury prevention in aircraft crashes: investigative techniques and applications" to review the status and future direction of the investigative techniques applied to aircraft accident investigation.

Survivability in aircraft crashes has been an area of major concern in military and civil aviation. Injuries occurred in survivable crashes can be prevented with improvements in aircraft effective crashworthiness, design criteria, personal protective equipment and flight escape systems. To effectively develop preventive strategies and equipment requires knowledge in the field of human tolerance to impact, aircraft crash dynamics and a deep understanding of the mechanism of injury.

The Lecture Series will focus on techniques for assessing injury crashes and the utilization of this data in the development of intervention strategies.

Topics to be covered will include:

— Human tolerance to abrupt acceleration

— Crash force estimation

— Principles of crash survivability

— Injury assessment

The main objective of this LS is to review among aircraft accident investigators, flight surgeons, managers, flight safety officers and engineers, the principles of injury prevention and survivability criteria in aircraft crashes.

This Lecture Series, sponsored by the Aerospace Medecine Panel of AGARD, has been implemented by the Consultant and Exchange Programme.

La prévention des lésions lors des accidents d'avions : les techniques d'investigation et leurs applications

(AGARD LS-208)

Synthèse

Le Panel de médecine aérospatiale (AMP) de la RTO (anciennement AGARD) a organisé le Cycle de conférences 208 sur "La prévention des lésions lors des accidents d'avions : les techniques d'investigation et leurs applications", afin de faire le point de l'état actuel des techniques d'investigation mises en œuvre suite aux accidents d'avion, ainsi que de leurs orientations futures.

La survie en cas d'écrasement au sol des aéronefs est un sujet de préoccupation majeur pour l'aviation civile et militaire. Les blessures non mortelles occasionnées lors des accidents d'avion pourraient être évitées moyennant l'amélioration de la résistance à l'écrasement des aéronefs, l'établissement de meilleurs critères de conception, la mise à disposition d'équipements de protection individuelle et le perfectionnement des systèmes d'évacuation. Le développement effectif de stratégies et de matériel préventifs passe par les connaissances en matière de la tolérance humaine aux impacts, de la dynamique des écrasements au sol, et de la compréhension des mécanismes de blessure.

LS 208 porte essentiellement sur les techniques employées pour l'évaluation des lésions dues aux accidents d'avion et sur l'utilisation de ces données dans l'élaboration de stratégies d'intervention.

Les sujets examinés comprennent entre autres:

— La tolérance humaine aux accélérations brutales

— L'estimation des forces en jeu lors des écrasements au sol

— Les principes de l'aptitude à la survie en cas d'accident d'avion

— L'évaluation des blessures

L'objectif principal de ce Cycle de conférences est de faire le point des critères régissant la prévention des blessures et l'aptitude à la survie lors des accidents d'avions dans un forum qui rassemble les enquêteurs d'accident, les officiers de la sécurité aérienne, les ingénieurs et les gestionnaires de la sécurité des vols.

Le Cycle de Conférences No. 208 de l'AGARD a été organisé par le Panel de Médecine Aérospatiale, sous l'égide du Programme des consultants et d'échanges.

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PREFACE

Aircraft Medical Investigation Techniques related to aircraft accidents have been identified as an area of major concern by AGARD. In this Lecture Series, Aircraft Accident Investigation is examined from several interrelated facets of varying interest to the flight surgeon, accident investigator, design engineer, flight safety officers, human factors specialist and aeromedical researcher in general.

The purpose of this Lecture Series is to address a critical aspect of the investigation related to the factors implied in the prevention of potential injuries among the occupants as a consequence of the impact, post-crash fire, heat, and toxic fumes.

These different aspects are dealt with in a series of lectures given by speakers world-renowned in their respective fields.

The first part of this publication concerns the basic accelerative forces most often encountered during crash events. We describe the acceleration vectors involved, how they may have an influence on the aircraft, and how the acceleration forces might be tolerated by the aviator.

The second part is mostly related to the physical and engineering principles which allow an understanding of an impact event and the available techniques for occupant protection. Also, we review the analysis of occupant kinematics by discussing the technical analysis of the material impacted and survivability limitations. Also, we discuss the physical analysis of impact and crash survivability, focusing on what happened during the mishap.

We review how to evaluate the tolerable deceleration forces and volume occupiable space consistent with life, including aircraft ejection situations. Examples and applications are also discussed.

A third block of this LS is devoted to answering questions such as, when did the injury occur, the nature of the forces that produced the injury, and their relationship to mishap forces. Injury types related to thermal, intrusive, impact or decelerative forces are discussed. In addition, we review aspects related to the collection of medical information that should identify the potential causes which can affect what happens to an individual, and the way in which the occupant moves in response to the forces applied, which may have a profound effect upon the nature and severity of the injury.

Finally the fourth part, concerns operational and practical applications.

Emphasis is placed on the application of injury data to improve aircraft and protective equipment design, to control energy dissipation during a crash in order to prevent injury to occupants, plus, the on-scene investigation techniques which provide adequate information related to survivor considerations of escape from the crashed aircraft.

Francisco Rios Tejada, MD PhD
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Lecture Series Direction

INJURY PREVENTION IN AIRCRAFT CRASHES: INVESTIGATIVE TECHNIQUES AND APPLICATIONS.
GENERAL CONCEPTS AND OBJECTIVES.

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INTRODUCTION.

For years an ongoing biomedical and crash injury field aircraft investigation and research have been conducted by a large variety of agencies taking advantage of the current experience developed from the automobile industry.
Accidents were investigated to reveal any of the wide range of human factors such as underlying illness, use of medications or drugs, fatigue, physical stresses, psychological and psychosocial stresses, types and extension of injuries received, causes of impact injuries, emergency escape from the aircraft, smoke and fire as related to survivability, environmental conditions and a number of other biomedical conditions that may have contributed to the crash or be related to occupant injury or survival.
A detailed analysis of injury sustained in aircraft impact would contribute to an understanding of the mechanisms involved and to know the design limitations of the human body to an impact and its survivability. While many similar injuries can be inflicted in a variety of ways, there are certain characteristic findings which suggest likely mechanisms of injury. For example, compression fractures of vertebral bodies in the low thoracic and lumbar spine typically occur as a consequence of forces acting approximately parallel to the long axis of the spine. Similarly, a typical finding in light-aircraft accidents involves blunt trauma applied to the head affecting the face predominantly and typically resulting from striking the head against a control wheel, instrument panel, console or other cockpit structure. These face and head injuries suggest

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mechanisms that occur independently of seat performance unless the back of a forward seat serves as a contact point for a rear passenger.

Aircraft medical investigation techniques related to aircraft accidents have been identified as an area of major concern by AGARD, and a monographic symposia was dedicated in 1992 to various aspects related to human factors, occupant injury, dynamic response, data analysis, injury and aircraft prevention and accident pathology. The Technical Evaluation Report (TER) of this conference recommended future education and training programmes dealing with specific topics related to accident investigation (1).

In 1990, 819 persons died in 2180 aviation crashes in the United States (2). Data regarding epidemiologic studies of pilot-related factors are needed to identify various risk factors of aircraft crashes (accident or incident). Those studies are of paramount relevance, but they must be done in conjunction with developments in crashworthiness research (3). Many accident investigators have reported that 70% to 80% of all deaths and injuries in crash decelerations are from face and/or head injuries caused by body flailing and head striking surrounding structures (4). Survival of an aircraft accident depends to a great extent on providing a crash-resistant container for the occupants, that is, an occupiable area that will withstand crash forces without crushing, collapsing, or disintegrating, and features such as the deformation of aircraft cockpit and cabin structures, the state of integrity and probable function of seats and restraint systems, probable impact of occupants against aircraft structures and the correlation of injuries with the direction and severity of impacts. Direct consequences of the investigation should lead to specific changes that may improve crashworthiness of the respective aircraft and in addition, significant operational lessons were drawn, and which, by application of what was

learnt, led to greater safety (5).

According to Shanahan (6) any effort in order to improve in-flight escape systems and better occupant protection against crash injury requires not only a thorough knowledge of the environment to which an occupant may be exposed in the event of an ejection or crash, but also an understanding of how much force a human can be expected to withstand in a given situation.

Personnel involved in the process of aircraft investigation must have an understanding of the basic principles of crash survivability.

A. Coordinate systems:

1. The aircraft and aircrew have corresponding coordinate axes, Roll (x), Pitch (y) and Yaw (z).
2. Force and acceleration are vector quantities and have both magnitude and direction.
3. Any applied force may be broken down according to its components directed along each of the three perpendicular axes.

B. Acceleration.

1. A key consideration in acceleration injury is the body's inertial response to an acceleration which is opposite and equal to the applied acceleration.
2. Acceleration may be described in G units.
3. Crash forces may be thought of as multiples of the weight of objects being accelerated.
4. A crash pulse is the time history of an applied force or acceleration and may be thought of as triangular in shape for this purpose:

$$\text{Peak G} = \frac{v^2}{32.2 \times \text{stop distance}}$$

C. A crash is considered survivable if:

1. The forces transmitted to the occupants do not exceed the human tolerance.
2. The structure around the occupants maintains a livable volume throughout the crash sequence.

D. Crashworthiness assessment:

The overall crashworthiness capability in terms of airframe load factors, crash resistance of seats and fuel systems and emergency egress provisions imply a human tolerance to abrupt

acceleration which is function of:

1. Magnitude of the acceleration.
2. Direction of the acceleration.
3. Duration of acceleration.
4. Onset rate.
5. Design and characteristics of the support and restraint systems.

Snow and al.(7) stated that survival and escape from a crashed aircraft, potentially in flames is a question of time, indeed most of the time no more than a few seconds, and this short period of time must be used in identifying the safest exit by overpassing numerous hazards, any of which might endanger the life of the crew or the passengers, i.e., smoke, fire and flames, blocking debris and physical barriers as a consequence of the impact. In addition to these extrinsic factors, their chance of survival is also influenced by physical and mental attributes of their own that may enable, or prevent, effective exploitation of the short time they have remaining.

Several factors might be involved and definitively influence the escape of passengers from a crashed aircraft or any emergency evacuation. These factors (7) may be grouped as:

1. Configurational:
Such as standard features of occupant environment controlling access to exits and evacuation flow rates. Seat size, seating density, number, location, indication and width of exits and cabin structure resistance to impact (seats and pins) could influence design factors.

2. Procedural:
Appropriate regulations regarding training among the aircrew and rescue personnel. New technologies such as virtual reality and advanced fire simulators will help in coping with procedural factors involved in emergency escapes from an aircraft.

3. Environmental:
Special features, such as the production of toxic fumes might greatly influence the evacuation procedures.

4. Biobehavioral:
Human behavior under conditions of extreme

physical and emotional stress should be considered, as well as biological, psychological and cultural attributes of individual passengers which influence agility and behavior. Sex, age, physical condition, experience, careful attention to emergency procedures briefing and mental agility can be taken as key behavioral factors.

OBJECTIVES.

This Lecture Series was developed to fulfill the technical training needs related to Injury Prevention in Aircraft Crashes of AGARD Aviation Medicine personnel involved in the investigation of the medical and pathological aspects of aviation accidents.

Objectives of this course are to:

1. Identify and understand the aspects related to impact effects and the accelerative force involved in an aircraft accident.

2. Provide support and assistance in the analysis of the mechanisms involved in the injury and death of aircraft occupants.

3. Collect and analyze medical and pathological data to support the determination of the factors that may play a definitive or contributory role in the accident.

4. To understand the application of injury analysis data to better research in protection and on scene accident safety escape.

Purpose of this Lecture Series was to address a critical aspect of the investigation related to the factors used in the prevention of potential injuries among the occupants as a consequence of the impact and post-crash fire, heat and toxic fumes.

CONTENTS.

This Lecture Series compiles a review of critical aspects of injury prevention.

First of all, we describe the acceleration vectors involved and how they may have an

influence on the aircraft. Secondly, we discuss how the acceleration forces might be tolerated by the aviator as a function of the acceleration onset rate, the G axis direction with respect to the body, the acceleration duration, the acceleration magnitude, the type of seat restraint, the physical characteristics of the aviator/occupant, the secondary impact of body parts with the aircraft, and distribution of force over body parts.

Also, we discuss the physical and engineering principles which allow an understanding of an impact event and the current available techniques for occupant protection. We analyzed the occupant kinematics and the impact and crash survivability focusing on what happened during the mishap. Also, we review how to evaluate the tolerable deceleration forces and volume occupiable space consistent with life. Applications of physical analysis of crash survivability are discussed in order to determine the impact sequence, the quantity of the deceleration pulses, the extent of aircraft structural damage plus occupant seating to establish the extent and nature of occupants' injuries related to cabin environment. Ejection seats are briefly mentioned as a special case.

Injury assessment should respond to questions such as, when did the injury occur, the nature of the forces that produced the injury and their relationship to mishap forces. Injury types related to thermal, intrusive, impact or decelerative forces are discussed.

The collection of medical information should identify the potential causes which can affect what happens to an individual, the way in which the occupant moves in response to the forces applied (crash dynamics, aircraft/cockpit and life support equipment) which may have a profound effect upon the nature and severity of the injury.

Emphasis is made on the application of injury data to improve aircraft and protective equipment design to control energy dissipation

during a crash in order to prevent injury to occupants. On-scene investigation should provide adequate information related to the survivor consideration of escape from the crash aircraft.

FINAL CONSIDERATIONS.

Unfortunately, as it was mentioned in AGARD CP 532, crash survivability is not the most important consideration in the design of an aircraft, and weight and cost do limit the degree of crashworthiness that can be practically incorporated into a design. Nevertheless when tradeoffs are made, it is imperative that developers understand the consequences of proposed compromises and ensure that cost, weight, performance and safety are weighted in their decisions.
According to Green and al.(8) the guiding principle of aircraft design is that it should be accomplished in a way that fits the job to the man rather than the man to the job and to apply the increased knowledge and techniques available nowadays to design the principles that may allow the crew to carry out their duties in the greatest safety and comfort and the passengers to cope easily with any emergency situation.
Finally, as a summary of this LS we should emphazise the relevance of the study and research related to specific mediators of injury. Their analysis is of paramount importance in order to improve airplane design and safety.
As a brief summary of the crash environment aspects we should consider, we describe an outline of the most critical factors involved (9,10):

1. Impact tolerance limits:
We can consider a survival accident, those in which the impact conditions are within human tolerances, and crew and passenger occupiable space remains reasonably uncompromised. In addition, postcrash factors must be such that successful egress is possible.
Factors involved are:
- Tolerable decelerative and impact forces.
- Occupiable space.
- Post crash environment.

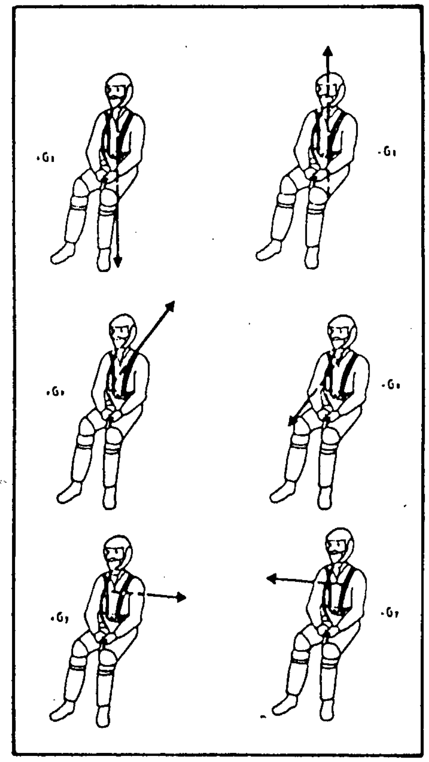
The specific mediators in crash survival are related to known velocities, stopping distances, ground and airframe deformation and decelerative forces on aircraft must be calculated. These factors classically have been classified in four main aspects:

- Container.
Related to the aircraft structures needed to provide an intact shell around the occupants.

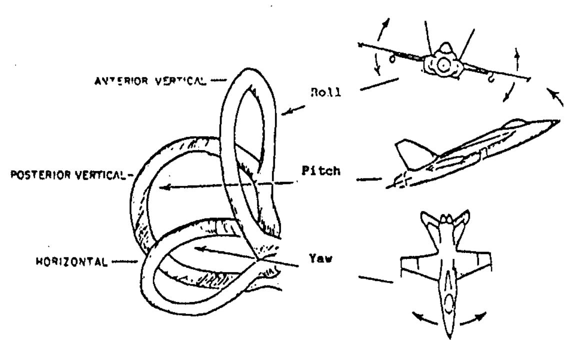
- Restraints.
Used to prevent the occupants, cargo and components from being thrown loose within the aircraft. Failure of any link in the restraint system results in a much higher chance of injury.

- Environment.
Related to the shape and configuration of potential striking structures within the aircraft.

- Energy absorption.
The dynamic responses during crash impacts determines how forces acting on the aircraft are transmitted to the occupants.



Acceleration classification



Aircraft-Human coordinate and attitude directions

- Post-crash factors. Generally associated to rapidly developed fires.

2. Injury analysis:

2.1. G forces.
Devoted to the characteristics of the decelerative forces involved. Different G patterns will cause specific results in each organ, from aortic transection to compression fractures.

2.2. Impact injury.
Injuries due to man-machine interaction or as a result of uncontrolled movements during the crash sequence, mostly associated to ejection.

2.3. Intrusive injuries.
Imply a loss of occupiable space due to intrusion of external elements as rotor blades, trees, wires, missiles or mid-air strike.

2.4. Thermal injury.
Differentiation between true thermal injuries and artifactual injuries.

3. Other factors to consider in the investigation:

3.1. Pre-existing disease.

3.2. Toxicology analysis.

3.3. Physiological factors.

3.4. Psychosocial factors.

3.5. Psychological factors.

3.6. Life support equipment.

3.7. Restraint and egress systems.

In conclusion, the analysis of injuries sustained by any aircrew or passengers should intend to examine the nature of the injuries and to establish the precise pathogenetic mechanism which lead to identifying the cause of the accident.
This effort will provide the aircraft with improved aircrew restraint inertia reels, airbag systems, crashworthy seats, improved egress training and improved egress procedures, which will provide the aircrew and passengers with a level of protection commensurate with the risk of operating aircraft in the military and civilian environment.

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HUMAN TOLERANCE TO ABRUPT ACCELERATION

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INTRODUCTION

Short duration accelerations resulting in injury or death can be inflicted not only on the occupants of vehicles involved in crashes, but also on pedestrians, sportsmen, persons falling from a height, and those exposed to explosions and bomb blast. The injury may be received when a person in motion comes into collision with a solid object or when an object or missile strikes a stationary person. Irrespective of the circumstances surrounding the accident, injury occurs when a person is exposed to forces of some magnitude for a brief period of time, and the degree of injury is related to the magnitude and duration of the applied forces.

Hence, the study of accidental injury can be summarised as what we hit, how we hit it, how long we hit it for, how many times we hit it and which part of the body is subjected to the insult. For effective injury reduction programmes to be introduced, an appreciation must be gained of the way in which accidents cause injuries, the nature of the forces contributing to the injuries and the characteristics of the type of accident under investigation.

SHORT DURATION VS LONG DURATION ACCELERATION

When assessing injuries incurred during aviation or automotive accidents we encounter occupants who have been exposed to high energies for very brief periods of time. The time course of an impact event is extremely short, being completed usually within 0.1 - 0.5 of a second. Early impact and deceleration studies on human and animal subjects, carried out in the 1930s by Siegfried Ruff in Germany, compared prolonged acceleration with impact acceleration and described the pertinent considerations in the study of the effects of impact accelerations to be the magnitude of the peak acceleration, the time of exposure, the momentum, the jolt, the nature of the forces of inertia and the site of application to the body.

The effects of short duration accelerations are related principally to the structural strength of the part of the body upon which they act and to the overall velocity change induced in the body. In contrast, intermediate duration accelerations are forces which persist for 0.5-2.0 seconds, as during ejections from aircraft, catapult launches and deck landings. Human tolerance to intermediate duration accelerations depends not only on the overall velocity change induced, but also upon the time taken to reach peak acceleration and upon the peak acceleration level attained.

Long duration acceleration, which can be experienced in various aircraft manoeuvres, imposes forces which last more than 2 seconds and have a duration of perhaps minutes. The human tolerance to sustained acceleration depends principally on the plateau level of the acceleration imposed on the body, as the response to long duration acceleration is due to the effects of physiological changes arising from distortion of the tissues and organs of the body and from alterations in the flow and distribution of blood and body fluids.

The profile of acceleration forces acting on an aircraft during a crash is determined by the manner in which the aircraft decelerates as its forward momentum is resisted by friction with the ground or by collision with stationary objects. If the structure of a crashing aircraft is crushed or deformed progressively, much of the kinetic energy of the crash is absorbed and the overall deceleration profile is relatively smooth. However, if parts of the crashing aircraft plough into the ground, the aircraft momentum is reduced more rapidly and peaks of abrupt decelerations of high magnitude are produced, with the highest peak values occurring when the aircraft strikes solid objects, such as rocks or buildings.

When an aircraft ditches, the forces acting on the airframe reflect not only the speed of the aircraft and its angle of incidence with the water, but also the orientation of the aircraft with respect to the wave front and the sea state at the time of the accident. There is often little attenuation from airframe deformation during a planned ditching as water tends to produce a uniform load distribution across the lower surfaces of the fuselage.

TERMINOLOGY

The following terms are encountered in the study of short duration acceleration.,

a) Speed is a scalar system concerned with distance and time, and describes the movement of a body without specifying the direction of travel.

b) Velocity is a vector and denotes speed in a given direction. A change of velocity can be a change in speed, a change of

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direction, or a change of both speed and direction.

c) Acceleration describes the change of velocity of an object and is also a vector quantity with both magnitude and direction. An applied acceleration is often referred to in terms of 'G', the ratio of the applied acceleration to the gravitational constant g ($9.81 m/s^2$).

d) Jolt, the rate of onset of acceleration, is the third derivative of acceleration and has the units of G/sec. Jolt is of particular importance in impact studies.

The direction in which an acceleration or inertial force acts on a human being is described by a three co-ordinate system in which the X axis describes forces acting in the fore and aft direction at right angles to the longitudinal axis of the body, the Y axis indicating laterally applied loads and the Z axis describing accelerations in the long axis of the body (Figure 1). It is important to distinguish between the applied force and the resultant inertial force as these act in opposite directions. For example, an upwards acceleration (applied force) displaces the internal organs and the eyes downwards towards the feet and this resultant (inertial) force is called $+G_Z$.

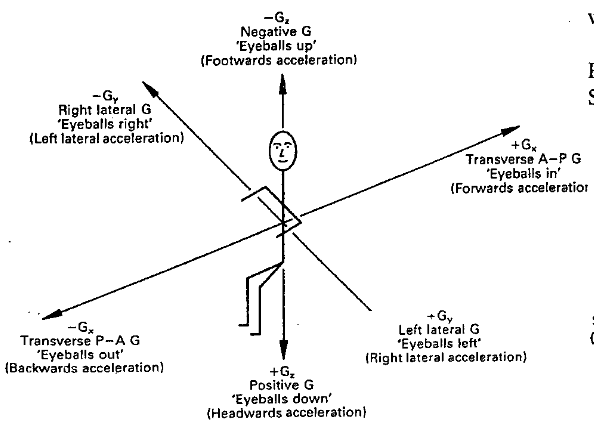

Fig 1. The standard AGARD aeromedical terminology for describing the direction of acceleration and inertial forces. The vectors indicate the direction of the resultant inertial forces.

SHORT DURATION ACCELERATION AND SITING POSITION

The tolerance of the occupant of an aircraft or vehicle seat to backwards acceleration ($-G_X$) depends critically on the effectiveness of the support provided to the front of the body by a restraint harness. If no obstacles are present within the flail envelope, the head will be flung down onto the chest and the arms and legs thrown forwards at right angles to the body.

Significant lateral ($+/-G_Y$) accelerations do not occur under normal flight conditions and in a crash the severity and type of injury received by the occupant is dependent on the restraint provided and the nature of any contact with airframe structures.

Significant $-G_Z$ acceleration can occur in crashes associated with a high sink rate. Tolerance to accelerations in this axis is influenced by the seat back angle, the sitting platform and the posture of the occupant. G_Z acceleration is reacted primarily through the buttocks and spinal column and the position of the occupant and the effectiveness of any restraint harness provided influence the incidence of spinal column injury.

NATURE OF SHORT DURATION IMPACT

Visco-elasticity is a material property whereby a change of stress occurs under constant deformation (stress relaxation) or a change in deformation occurs under constant load (creep). All biological tissues, even hard tissues such as bone have the property of visco-elasticity and will break under different loads depending on the rate of application of the load, the nature of the force and the time over which the force is applied. Figure 2 illustrates the concept of visco-elasticity with respect to human bone and illustrates that bones may sustain, without breaking, a higher force rapidly applied and withdrawn than they may sustain when even a lower force is more slowly applied.

RATE DEPENDENCY OF MAMMALIAN BONE STRUCTURE

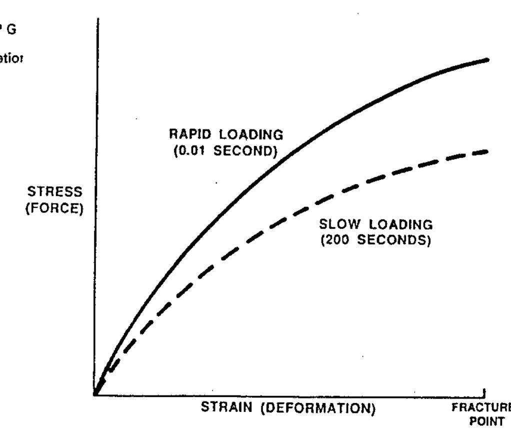

Fig 2

Physical damage incurred during an impact is due to the relative movement of parts of the body coming into contact with an object. The nature of the impact and the configuration of the struck object or surface influence the distribution of the stresses within the body and the damage seen after the impact. The initial velocity change of the body in contact with an accelerative force can be supersonic, subsonic or trans-sonic.

When loads, such as a bullet fired from a gun, travelling at supersonic speeds impact the body, the shock wave set up carries energy that moves through the body faster than the speed of sound in the body. This energy, travelling at supersonic speeds, is concentrated in a shock wave front, and, being concentrated in a thin layer in the body, results in a concentration of strain energy that has a great potential for injury. A fast moving, blunt load that does not penetrate can still cause shock wave damage.

Transonic velocities produces stress waves which move in the body at sonic speeds. These stress waves may be concentrated into a small area and cause concentrated damage in that area. They may also be reflected at the borders of organs and tissues, causing even greater damage. The complex phenomena of shock and elastic wave reflection, refraction, interference and focusing are made more complex in the body by the fact that different organs transmit sound at different speeds.

During the type of impact that may be found in a vehicle or aircraft accident, vibrations can be induced in the internal tissues and organs of the occupants. These vibrations result in a dynamic stress which is higher than the stress that would have existed had the load been applied statically. A force may be applied very slowly and some impact velocities are so slow that they are almost static and all the tissues and organs of the body at every point respond to the static load with static stress. In general terms, the slower the application of the load, the smaller the stress induced, and the greater the rate of application, the larger the stress induced. As the rate of application increases, induced vibration may cause additional damage and even further damage may be sustained from stress concentration of elastic waves.

The input of energy into a system results in stress and its associated strain. The strength of a material, that is, the maximum stress a material can bear without failure, depends on the rate of change of strain. Thus, the limit of safety, where the maximum stress remains below the critical limit of strength, depends on the rate of loading.

When considering the strength and tolerance of the human body to applied loads, the magnitude of the stress and its rate of application must be taken into account. The static stress distribution in the body under external load (e.g. the inertia force due to the deceleration of the aircraft or vehicle) must be determined first, followed by any dynamic amplification due to vibrations within the body or stress concentration due to elastic waves and shock waves. In other words, the strength of an organ or a tissue in the body depends not only on the magnitude of the stress, be it static or dynamic, but also on the type of stress and whether it is uni-, bi-, or tri- axial.

When a vehicle or aircraft crashes, the energy involved is kinetic energy and the vehicle stops once this kinetic energy is used up. However, although the vehicle may stop, the occupants within the vehicle will travel along the same trajectory until they, too, are stopped either by the operation of a restraint system or by contacting part of the interior of the vehicle. The forces acting on the occupant may be significantly reduced in the presence of effective restraints, energy attenuating seats and well-designed occupant space and increased if the occupant experiences little deceleration during the early part of the crash through absent or ineffective restraint or poor seat design.

HUMAN TOLERANCE TO SHORT DURATION ACCELERATION

Tolerance is defined in the OED as "the willingness or ability to tolerate" and "the capacity to tolerate something, especially...environmental conditions without adverse reaction". The definition of the human tolerance levels to short duration accelerations is not a simple task due to the variability of individual response and the need to define the level of injury or discomfort which is considered acceptable. For convenience, short duration acceleration forces are often separated into three broad categories: tolerable, injurious and fatal. In this classification, tolerable forces may produce minor superficial trauma such as bruises and abrasions which do not incapacitate, injurious forces result in moderate to severe trauma which may or may not incapacitate and fatal injuries are self-explanatory.

In a vehicle crash the instantaneous change in velocity, Δv, is the best predictor of injury severity. The probability of an occupant receiving injury or death increases with an increasing Δv, although the relationship between Δv and injury severity is non-linear and influenced by physiological and anatomical variabilities of the occupant.

In 1962 Kornhauser and Gold applied the "impact sensitivity method", developed in the mid-1940s to describe the performance of ballistic devices such as impact switches, to animate beings. This forms the basis of the graph at Figure 3 which plots the logarithm of Δv (ft/sec) against the logarithm of acceleration (G). Fig 3 Inspection of the graph shows that, in general, an acceleration averaging 20G with a velocity change of 80 ft/sec must be exceeded for injury to occur in well restrained humans subjected to accelerations transverse to their long axis (G_X). If the duration of the typical aircraft crash is similar to that of an automobile crash, 0.1 seconds, then inspection of the graph shows that the time epoch of the typical crash occurs at the break between the vertical line of tolerance for acceleration (20G) and the horizontal line of delta v (80 f/s). In other words, at the usual impact duration of 0.1 secs, less than 20G and 80 ft/sec velocity change is probably survivable, or 200G is possibly survivable with a duration of 0.2 secs, with a Δv below 80 ft/sec, 20G is possibly survivable for 10 secs even at velocity changes of 10,000 ft/sec

In general, the following have been accepted as the upper limits of tolerable acceleration forces. However, human variability and differing environmental conditions may significantly alter the ability of an

individual to withstand abrupt decelerations in a particular aircraft crash, therefore all estimations of human tolerances to impact must be seen as approximate.

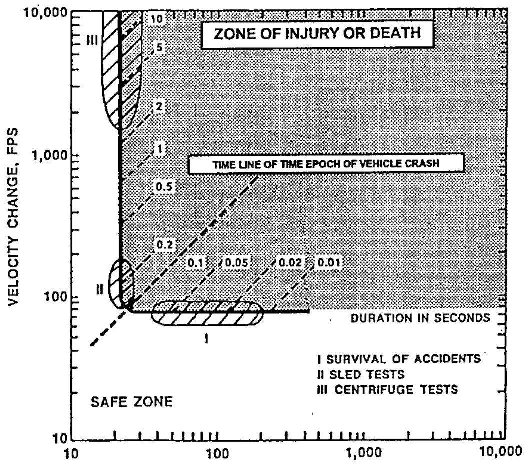

Fig 3 Average Acceleration, G Units
(After Kornhauser and Gold)

$+G_Z$ acceleration. Acceleration in this direction is usually associated with ejection from aircraft and is included here for completion. It has been estimated that an acceleration pulse of approximately 25G for about 0.1 sec is within tolerable limits. Minor injuries, including compression fractures of spinal vertebrae can occur within these limits, but such injuries are not usually incapacitating and should not prevent escape from the aircraft.

$-G_Z$ acceleration. Experimental evidence is that a restrained, seated subject is able to withstand an abrupt $-G_Z$ acceleration of about 15 G for 0.1 sec without serious injury.

$-G_X$ acceleration. For accelerations in this axis, it is considered that 45 G sustained for 0.1 second or 25 G for 0.2 sec are both within tolerable levels for a fully restrained, seated occupant. Some injury may occur, but this should not be incapacitating.

$+G_X$ acceleration. The tolerance limits for occupants seated in this orientation have not yet been accurately defined. It is assumed that, with a suitable headrest and restraint, that the limits for this orientation will be higher than for forward facing occupants.

Gy acceleration. Tolerance limits for lateral impacts are not well defined, but it has been suggested that limits of 11-12 G for 0.1 sec are tolerable and limits of 20 G for 0.1 sec are survivable for an occupant restrained by a harness into the seat.

FACTORS AFFECTING HUMAN TOLERANCE TO SHORT DURATION ACCELERATION

Magnitude and direction of applied force. In general, under similar conditions, the longer the duration of the impact pulse the lower the acceleration level that can be tolerated. For example, a chest-to-back acceleration of 45G can be voluntarily tolerated by some subjects if the pulse duration is less than 0.044 seconds, but only 25G is considered tolerable if the pulse duration is increased to 0.2 seconds.

Rate of onset of applied force. If the conditions of the impact are the same, the lower the rate of onset of the acceleration, the better the impact will be tolerated. For example, if the rate of onset of the acceleration is 1000G/second in a $-G_X$ impact signs of shock will be evident, but if the rate of onset is slowed to 60G/second for an impact of the same magnitude, no signs of shock will be seen. The effects of some rates of onset of acceleration are related to the natural resonant frequency of the whole body, various body organs and to the compliance of the visco-elastic systems of the bones, joints and ligaments.

Direction of applied force. The body can withstand much greater forces applied in the G_X axis due to the larger surface area of the body in this orientation. Accelerations in the G_Z axis place greater strain on the organs suspended in the body cavities and the tolerance to impact is reduced. The limited research on the effects of G_Y impacts indicates these to have the lowest tolerance limits.

Site of application of acceleration. In general, parts of the body, such as the back and buttocks are more able to withstand a given force than the more vulnerable parts like the limbs and head.

OCCUPANT CHARACTERISTICS AND TOLERANCE TO IMPACT

There are a number of problems which must be resolved to identify the limits of human tolerance to impact. Human beings are not only divisible by gender, each with its own set of related characteristics, but are infinitely variable in age, race, build, fitness and freedom from disease. Hence, attempts to quantify impact tolerance limits have resulted in approximations and generalisations making it necessary in any one accident, to analyse occupant injury mechanisms individually.

Not only are human beings infinitely variable, but each crash is also a unique event (as is each ejection from an aircraft). Whilst it can be said in general terms that aircraft tend to crash by flying into the ground, stalling and falling, or impacting buildings or barriers, environmental conditions, impact surfaces and the parameters of the aircraft will differ from accident to accident.

The tolerance limits for fatality and injury causation have been derived from research carried out in a variety of institutions using a multiplicity of experimental devices and techniques. Impacts have been carried out on animal subjects, cadavers, and live volunteers, but the limited numbers of impacts using these scarce

resources and the variability of the subjects themselves has allowed only an approximation of tolerance limits. The utilisation of Anthropometric Test Devices (ATDs) to provide repeatable impact conditions has suffered from the employment of a number of ATDs, each with its own characteristic responses and limitations. The protocols, measurements and recording techniques employed in these research programmes have been many and varied, making it extremely difficult to compare the results obtained with either other ATD tests or with tests using biological subjects.

ANATOMICAL AND PHYSIOLOGICAL ASPECTS OF IMPACT TOLERANCE

Injury can result from a direct blow to the body by a solid object, or from an indirectly transmitted force, such as when the humerus or clavicle is fractured from an impact transmitted up the outstretched arm during a fall. Either mechanism of injury can result in damage to the skeletal framework of the body or to the soft tissues and internal organs.

Skeletal Injury. Damage to the bony skeleton of the body, including the joints, is the most common injury seen in the crash environment. Injuries to the upper and lower extremities are particularly common, and these do not appear to be reduced by the provision of effective restraint harnesses. The bones of the skeleton can be classified into four main groups, each of which has a characteristic response to an applied force or load:

a. Long bones are tubular, with dense cortical bone surrounding a medullary cavity filled with trabeculated bone. The trabeculated bony core in the cartilage covered expanded epiphyses of long bones is able to absorb energy when put under load and the hollow tubular shaft resist compression.

b. The short bones of the carpus and tarsus (wrist and foot) are roughly cuboidal in shape, although some may have more than one surface. The short bones permit limited multi-directional motion when under load.

c. Flat bones which have two plates of dense bone either side of a middle layer of softer, marrow filled bone, are represented by the bones of the skull, sternum and scapula. These bones have great stiffness and strength for their weight, both in torsion and bending, and are only be broken by a direct impact.

d. Irregular bones such as those which make up the jaw and the bones of the face.

e. Bones such as the vertebrae which have features common to more than one bony type.

Skeletal fractures may be the result of torsion, tension, shear and compression, or combinations of these forces. The direction of the forces and the rate at which they are applied, together with an estimation of the loads involved, may be obtained from an examination of the fracture type.

Joints. Joint disruption can result in an unstable joint, or one where the range of movement has become either restricted or more than normally mobile. The application of a force which stresses a joint beyond its normal range of motion results in the failure of the ligaments, tendons, and the joint capsule.

The Abdominal Cavity. The peritoneal cavity is the largest cavity in the human body with contents varying in structure and consistency from the highly vascular and easily damaged liver, spleen and pancreas, to the gas containing stomach and intestines. Almost the entire digestive tract and most of the genito-urinary tract is contained within the peritoneal cavity or covered by peritoneum. The major blood vessels, the aorta, iliac vessels and the inferior vena cava course through the abdominal cavity, together with the autonomic ganglia, plexuses and nerves and the splanchnic nerves.

The abdominal cavity reacts to an impact as a fluid-filled or hydraulic cavity and the force of a blow to any part of the abdomen is transmitted to all organs and structures within the abdominal cavity virtually unchanged. Some dampening of the pressure waves generated by an abdominal impact occurs through compression of the air and gas in the intestines and stomach, and some through the action of the muscles of the abdominal wall and the muscular layers of the various viscera. Hence, a potentially rapidly fatal rupture of the diaphragm, liver or spleen can occur from blunt trauma to any part of the abdomen.

Studies to delineate tolerance levels to non-penetrating abdominal trauma are limited. The viscous injury criterion proposed in 1987/1988 by the General Motors Research Laboratories was derived by multiplying the velocity of the abdominal deformation and the amount of abdominal deformation, and relates primarily to the production of liver damage. As the liver can be damaged without injury to other intra-abdominal organs being incurred, and intra-abdominal injuries can occur in the absence of liver damage, this criterion is of limited use as a predictor of abdominal injury thresholds.

Blunt trauma can result in abdominal injury by several mechanisms such as pressure wave transmission, compression and shear forces and the visco-elastic properties of the individual organs influence the tolerance to impact and blast. However, it would appear that intestinal injury in vehicle crashes occurs mainly in response to submarining under a lap belt.

The Chest. In vehicle trauma, the chest is the most commonly injured part of the body after the head and limbs and impact injuries to the chest are either fatal in a short period of time or survivable as all the contents of the chest are vital to life and injury to any one of them may be fatal. The response of the chest to impact

is determined by its visco-elastic properties, since the probability of injury to the chest or the thoracic contents is dependant on the time period over which the force is applied as well as to the magnitude of the applied force.

Major life-threatening injuries to the chest compromise either the respiratory or circulatory systems, and can result in hypoxic brain damage or death. Severe decreases in the amount of oxygen available for transport by an intact circulatory system can result from an inhibition of the mechanics of breathing resulting from damage to ribs and diaphragm as well as from the alterations of lung architecture associated with pneumothorax, haemothorax and lung contusions.

Disruption of the circulatory system, with potentially fatal decreases in the blood volume available for oxygen transport, can be the result of blunt trauma to the chest. Non- penetrating cardiac injuries (ruptures of the myocardium, cardiac septa, pericardium and valvular apparatus) and rupture of the aorta are the most frequently seen injuries at post-mortem examination of the victims of vehicle trauma.

Head and Face. The head is the most frequently injured region of the body in vehicle crashes where the occupants have been restrained by a three-point belt, and the predominant cause of death in vehicular crashes. The definition of head injury tolerance is fraught with difficulty and still requires clarification. In pursuing the study of head and brain injury, some researchers have equated head injury with brain injury, whilst others have related head injury to fracture of the skull and as it is possible to have brain injury without a skull fracture, and skull fracture without brain injury difficulties arise in the correlation of the results of observations and experiments. The concept of a single Head Injury Criterion (HIC) derived from a small number of impacts on cadavers and an assessment of head injuries which does not allow for non-contact head injuries and does not distinguish minor head injuries from major brain trauma has been shown to be inappropriate but in the absence of a suitable replacement standard is still referred to in head impact studies.

Head injuries and the mechanisms of injury can be classified as follows.

a. Contact Injuries of the Head. These require a blow to the head, but subsequent motion of the head, if present, is not related specifically to the injuries which are caused by skull deformation.

i. Deformations near the site of the blow can result in skull fracture, extradural haematoma or coup contusion

ii. Deformations distant from the site of impact can result in vault and basilar fractures.

iii. Travelling wave injuries can occur leading to contracoup contusion and/or intracerebral bleeding.

b. Non-contact injuries of the Head. These injuries will only occur if the head is accelerated. They require motion of the head, but do not require the head to strike an object or for the head to be struck by an object. Angular acceleration appears to be more causal than linear acceleration, and lateral motion appears to be more causal than fore and aft motion. These injuries are the result of strains (deformations of the tissues from external force loading) which may be:

i. Surface strains resulting in subdural haematoma, contracoup contusion, "intermediate" coup contusion.

ii. Deep strains resulting in concussional syndromes and diffuse axonal injury. Almost all diffuse axonal injury results from vehicular crash, which has a relatively long acceleration, in contrast to accidental falls and assaults which have an impact the duration of which is more brief than that seen in crashes and therefore more commonly associated with sub-dural haematomata.

Injuries to the brain are exacerbated by concomitant injury elsewhere in the body. The loss of circulating blood volume from haemorrhagic or other shock decreases brain oxygenation and leads to hypoxic-ischaemic damage.

The difficulties encountered in research to derive the tolerance levels for injury to the human brain are legion. Cadaveric studies are limited in their availability, standardisation and repeatability. Animal studies suffer by the need to interpret and scale the results of experiments with respect to human anatomy and physiology, and ATD impact tests are limited by a lack of biofidelity. The development of computer models for the prediction of damage to the brain and tolerance to impact has been hampered by the complexity of the human skull and brain which are not homogeneous, are compartmentalised by the anatomy of the skull and the dividing membranes and subject to pressure fluctuations transmitted by the CSF.

The Spine. Back injuries incurred during an aircraft crash may involve the musculo-skeletal structures of the vertebral column and/or the spinal cord itself. When

considering the evidence for the mechanism of injury to the vertebral column, during the inspection of x-ray films and clinical examination of accident victims to determine the mechanism of injury, consideration must be given to the fact that post accident appearances will not indicate the maximum deformation that occurred at the time of maximal loading.

The determination of a mechanism for vertebral column injury in any one accident is further complicated by the variation in response to identical applied loads which arise from individual anatomical and physiological characteristics. The pattern of injury will depend on which of the elements in the vertebral column is the weakest link in a particular individual, such as when intervertebral disc lesions are affected by the degeneration of the disc which occurs with increasing age. Injuries from the same applied loads may be modified in different individuals by the action of the vertebral muscles, especially if pre-tensioning of the vertebral muscles has taken place prior to the impact.

The motion of the spine is complex and occurs as coupled motions. Lateral bending involves rotation about the horizontal and vertical axes as well as translation perpendicular to the horizontal plane, hence lateral bending may cause any combination of transverse shear in the horizontal plane, rotational shear about the vertical axis and tensile and compressive stresses in the vertebral bodies. Furthermore, similar injuries may be produced by a number of different mechanisms, such as anterior lip fracture which may result from either hyperextension or hyperflexion with compression.

The tolerance of the vertebral column to impact in not uniform down its length with, in general terms, fractures of the cervical vertebrae are less stable than those of the lumbar vertebrae. Stability of the vertebral column following impact injury is paramount in determining the overall survival of the casualty. High cervical fractures with instability of the neck are likely to result in injury or transection of the spinal cord and high spinal cord injuries are often fatal or result in quadriplegia.

The majority of the injuries to the vertebral column from vehicle accidents involve the thoraco-lumbar spine. The response of the thoracic vertebrae to impact is modified by the presence of the ribs, whereas the increasing size of the lumbar vertebrae and the orientation of the facet joints of the lumbar vertebrae lead to increased stability of the lower vertebral column. The forces required to cause fractures or fracture dislocations of the thoracolumbar spine are very large due to the size of the vertebral bodies and supporting ligaments.

An awareness of the most likely sequence of events in a particular accident, with some assessment of the probable kinematics of the occupant, will allow the determination of the most likely mechanism of a spinal injury. Consideration must be given to the type of restraints employed as the different belt configurations are associated with characteristic injuries such as hyperflexion over a lap belt or rotation and hyperflexion over a three point harness.

SURVIVABILITY AND TOLERANCE TO IMPACT ACCELERATION

It can be seen from the above that the quantification of survivable levels of impact acceleration is fraught with difficulty. The circumstances surrounding any aircraft accident vary from accident to accident in response to environmental influences, the nature of the emergency and the configuration of the aircraft at the time of impact. The male and female occupants of these aircraft are not "standardised" and cover the full anthropometric range of the human race. The occupants will vary in their pre-accident fitness, freedom from underlying disease or deformity and susceptibility to injury. They may be unrestrained, will be seated on a variety of seats and will be wearing non-standard clothing. Where restraint harnesses are employed, these will come in a many different materials, configurations and attachments, be in varying states of repair and will have been in use for an indeterminate length of time.

Any attempt to standardise human tolerance limits from actual accidents where so many variables exist needs to be circumspect and confined to broad limits only and researchers in the field of human bio-engineering and medicine have been seeking alternative sources of information on human impact tolerances. Information has been gained from human experimentation, cadaver studies, animal studies and impact studies using a diversity of ATDs. However, all these approached have suffered from the limitations inherent in using scarce and costly resources and the lack of standardisation of subjects, impact parameters and test and recording methodology. The development of increasingly sophisticated ATDs and recording devices able to withstand repeated impacts has continued to provide a tool for research into the effects of short duration accelerations but as with live data, the "human tolerance limits" derived from ATD impact research must also be treated with some circumspection.

No experimental programme will be able to fully reproduce the conditions met in an accident and data from all experimental programs requires validation against known injury from painstakingly researched real accidents. Live experimentation is limited to non-injurious levels and ATDs are exactly what they are. Mathematical models are being developed to assisting the understanding of the nature of the forces encountered during accidental impact and although these and the new generation of ATDs are becoming more biofidelic, they are not human beings. Not only do neither mathematical models nor ATDs break in an impact, but they lack the internal structure of the human body and are unable to realistically mimic the result of impact accelerations on organs and body tissues. Most importantly, they do not bleed.

An accident may be considered survivable in terms of the injuries recorded as a result of accelerative forces, but death may ensue from another cause, such as a penetrating injury and internal or external haemorrhage. A survivable accident may become unsurvivable in the presence of a minor head injury causing a short period of unconsciousness and the failure to escape the post crash fire or effect an underwater escape. Relatively minor but incapacitating limb injuries can similarly prevent survivors of the initial event surviving the post crash sequelae.

In other words, the outcome of any accident will depend not only on the nature of the injuries directly resulting from the body' response to impact, but on complicating factors from any injury caused by the deformation of the airframe, penetrating injuries, environmental factors such as fire or water, and the rapidity with which emergency services can respond and the provision of expert medical care. However, research into injury mechanisms has increased the body of knowledge concerning the effects of crashes on occupants, the effectiveness of various configurations of restraint harnesses and the limitation of acceleration level by appropriate seating and airframe construction. The increasing understanding of the way in which abrupt accelerations can distort and damage human beings is leading to improvements in the design of aircraft cabins and seating plans, as well as to the provision of safer cockpits. The interchange of information between researchers in the field of aviation induced accident injury and automotive related accident injury is leading to improvements in the design of safer cars as well as safer aircraft.

However, at present we know a great deal about the performance of certain test dummies and the tolerance levels of these dummies for abrupt accelerations. We also know a great deal about the behaviour of some sophisticated mathematical models when programmed in a crash scenario, but what we still do not know are the tolerance levels of real human beings.

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PRINCIPLES OF CRASH SURVIVABILITY

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HISTORICAL APPROACHES

A comprehensive review of the history of impact protection is clearly beyond the scope of this review. The interested reader is referred to the bibliography for the chapter on Biodynamics: Transitory acceleration in DeHart's Fundamentals of Aerospace Medicine. Suffice it to say here that the endeavor to protect occupants in aircraft crashes began with the pioneers of aviation and continues to the present day. It has met with considerable success but remains limited by the remarkable violence that can be wrought when fast moving objects meet fixed ones. The human body has a meager ability to cope with such violence without assistance and practical methods of assistance can only go so far.

The basic lines of attack on the problem have generally been to provide a container to surround the occupant, provide a seat and restraint to hold him there, limit the accelerations of the container to tolerable levels, provide personal protective equipment such as helmets, and control for post-crash factors such as fire or water landing. Ejection seats, capsules or modules were something of a special case, since they were intended to allow the occupant to avoid the crash altogether. However, they posed their own set of risks such as the ejection accelerations, windblast, altitude exposure, parachute opening shock, parachute landing, and a host of others. They made a real contribution in many cases, but they didn't make the problem of impact injury go away.

Historically, the function of the container was to prevent the occupant from being struck by something from the outside and to keep him from being crushed like a grape. The restraint was thought of as a means to keep him from being ejected from the container and to prevent harmful impacts with the inside structure of the container. The accelerations of the container were expected to be limited to tolerable levels through the use of crushable structure serving the function of our deforming balls in collisions as described in the earlier portion of this paper. Helmets were expected to do the same thing for head impacts. When injury did occur, investigators would ascribe the occurrence to deficiencies in the protection or crash severity beyond the range in which protection could be reasonably relied upon. This was often considered a simple decision, particularly in very severe crashes with aircraft disintegration and multiple, extreme injuries.

The problem really arose in assessing injury in severe crashes where it seemed people might, or ought to, survive. Some have thought in terms of crashes being survivable or non-survivable. Death or serious injury in a survivable crash meant that a deficiency existed in protection. When people survived non-survivable crashes, it was ascribed to the realm of the miraculous. Human tolerance data for crash accelerations were based on tests with volunteers or cadavers in which maximum acceleration was referenced to the vehicle's center of mass or some similar point. All these approaches fail to consider the ways in which injuries come about.

The fact is, there is no magic dividing point between survivable and non-survivable crashes. Instead, there is an increasing probability of death with increasing severity for given kinds of crashes. Furthermore, injuries are produced in various ways and are not simply or most proximately related to the peak acceleration of the vehicle center of mass. A realistic view of crash survivability must be based on an appreciation of how injuries are actually caused and the techniques available to interrupt the process.

The Physical Basis of Injury: Stress-Strain Relationships

Impact injury typically refers to structural disruption of biological tissue as a result of a short duration physical event. The duration of an event that can be termed an impact usually is less than a second or two. The best distinction between an impact and a sustained event however, is that the body's principal response to an impact doesn't develop a sustained component. Impact causes tissue disruptions by placing stress on the tissue. Tissue can be stressed in different ways. Force which tends to compress tissue produces compression stress. The negative of compression stress is tension or distraction stress, produced by force which tends to pull tissue apart. A single number positive or negative can therefore be used to describe compression-tension stress.

It is important to note that compression force and the compression stress it produces are two different things. The same force can produce a wide range of stresses. If I apply a force of 40 newtons to your thumb using a thimble, it will be less stressful than the same force applied using a needle. Compression-tension stress is defined as the force per unit area over which it is evenly applied. This stress therefore varies with the cross-sectional area of the compressed structure.

It is somewhat unfortunate that stress is so difficult to measure, particularly for internal stresses within tissues. As a result, stresses on similar anatomic structures are usually compared by assessing the forces that produce them. For example, compression stress in the cervical spine may be assessed by measuring the axial force measured with a load cell placed in the neck of the dummy. This may allow meaningful comparison of internal stresses in the neck for similar neck orientations for similarly sized subjects. However, the internal

Paper presented at the AGARD AMP Lecture Series on "Injury Prevention in Aircraft Crashes: Investigative Techniques and Applications", held in Farnborough, UK, 24-25 November 1997, and Madrid, Spain, 1-2 December 1997, and published in LS-208.

stresses will change for the various load-carrying components of the vertebral elements if the same axial force is applied with varying degrees of cervical flexion. It is therefore a hopeless oversimplification to simply state that injury tolerance is so many newtons of axial force on the neck.

There are several other reasons why such a description is an oversimplification. One is that axial compression or tension stress is not the only kind of stress that can be placed on the neck or on other tissue. Mathematically, there are enough other kinds of stress that can be placed on a structure such as the neck or a femur to require a total of six numerical values for a complete description, namely

Compression-Tension Load
Fore - Aft Bending
Left - Right Bending
Fore - Aft Shear
Left - Right Shear
Clockwise - Counterclockwise Torsion

In general, real world tissue stresses in impacts involve some of each, but there are often one or two primary stresses. To complicate matters further, the significance of any given stress will typically vary with the orientation of the stressed structure as with neck flexion, for example.

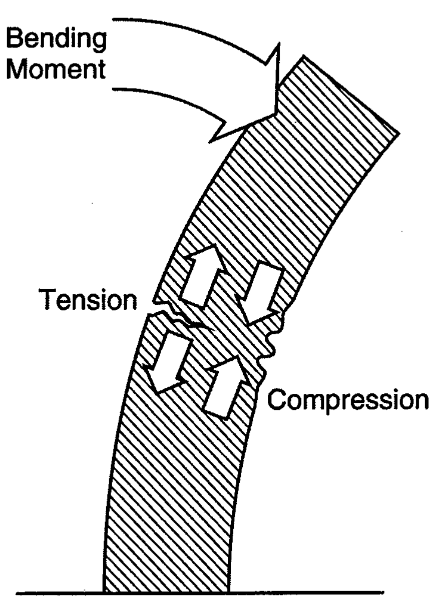

Figure 1. Example of forces and response of a material.

Bending stress is not produced by force but by torque which is measured in newton-meters or foot-pounds. Bending of a beam structure results in a number of internal stresses. For example, bending will place one side in tension and the other side in compression, as shown in Figure 1. Since it may occur in two dimensions, it requires two numbers for its description. The resulting stress also varies with the cross-sectional area of the bent structure.

Shear stress is produced by a non-aligned force couple which, if aligned, would have produced compression or tension. Since the force couple is non-aligned, it tends to produce slip. The name for shear stress is the same as that applied to a pair of shears for cutting cloth, with the stress being the same. The amount of shear stress for a given force couple again varies with the cross-sectional area. Since it is also two dimensional, two numbers are required for its description.

The final stress to be considered is torsion or twist. Only one number is necessary to describe it since it is one dimensional. Axial torque produces it and the resulting stress depends again on cross-sectional area. Internally, it produces local tension, compression, and shear.

Since all these stresses are typically involved to varying degrees in producing an injury such as a long bone or neck fracture, it is clearly inadequate to simply ask how many newtons or pounds were necessary to produce the fracture. Another reason that question is inadequate relates to the concept of strain.

The Physical Basis of Injury: Strain

Strain is the degree of deformation produced by a stress. Compression stress produces strain which decreases an axial dimension. The strain is measured as the amount of decrease in the dimension divided by the initial value. Bending stress distorts tissue about a cross-axis. Torsion stress produces angular distortion about the long axis. Shear produces distortion that might best be described as slip.

Resistance to strain is known as stiffness. The stiffer something is, the harder it is to deform. Most biological tissues and many other structures have stiffnesses which vary with the rate of change of the stress. If you apply stress very slowly, these objects behave as if they were less stiff than if you increase the stress rapidly. This property is known as viscoelasticity. As a result, the same stress can produce different amounts of strain depending on how the stress is applied. This is another reason why injury cannot be simply related to a single stress level or the force that produces the stress. Biological tissues are capable of experiencing varying degrees of distortion or deformation without being disrupted. When the stress is removed, the strain decreases. Ultimately, however, enough stress can be applied to create strain which causes permanent disruption of tissue which is the condition of injury. The disruption generally occurs in the following manner. Increasing stress results in increasing strain until a point where the tissue yields. From there on, the tissue's resistance to being deformed decreases and the strain increases even as the stress falls off. The point of transition is called the yield point or the yield strength of the material. On the near side of the yield point, permanent injury typically does not result. A continued attempt to impose stress beyond the yield point results in increasing injury up to structural disruption. Injury then is simply strain beyond the yield point.

One reason all this is important in understanding injury is that strain takes time. Suppose you apply a stress to a material sufficient to produce strain past the yield point, but you remove it rapidly before yield strain is achieved. Catastrophic injury would then be avoided. Tissues can tolerate normally injurious stress levels if they don't have to tolerate them for long.

Even without developing the detailed mathematics of stress - strain relationships for all the kinds of stresses, we now have enough understanding of the injury process to appreciate the need for increasing the sophistication of our descriptions of the forces that produce injury and the body's ability to resist being injured. It is not adequate to simply specify some level of force or acceleration as being injurious or tolerable. You must understand the kinds of stresses imposed by the force, the duration of the force, its variation with time, the condition, characteristics, and orientation of the stressed material, and the potential interaction of other stresses. The wide variation in data on human tolerance to injury can be better accounted for when these factors are considered. They similarly must be considered in assessing an accidental injury event.

Injury Mechanisms

Injury mechanisms are descriptions of the process by which an injury occurs. Defining the mechanism of an injury ultimately involves specifying the principal stress or stresses which proximately produce an injury. Even though six kinds of stresses may be applied to a neck which sustains an injury such as bilateral locked facets, the principal injury producing mechanism is consistently found to be a bending stress resulting from forced forward flexion. Increasing amounts of concurrent axial compression increase the likelihood of associated facet fracture with the dislocation and associated vertebral body damage as well.

As an example, consider the spiral femur fracture portrayed in Figure 2.

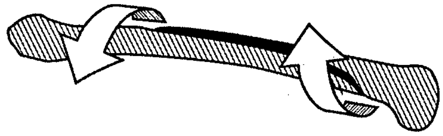

Figure 2. Spiral femur fracture.

The mechanism is principally torsion, with associated compression or tension potentially interacting with it. By contrast, the fracture in Figure 3 with the characteristic "butterfly" fragment is a classical bending fracture. We can say even more about the mechanism. Since we know that bone fails first in tension, we know that the failure will originate on the side of the bent bone that is placed in tension rather than compression. The fracture will then typically propagate along two diverging planes as the two ends slide around or push out the free fragment. We can therefore specify not only a bending mechanism, but also the direction of the bend, with the apex of the fragment pointing toward the tension side of the bend.

Other mechanisms can be found in the literature or often deduced from the characteristics of the injury when viewed from a stress-strain standpoint.

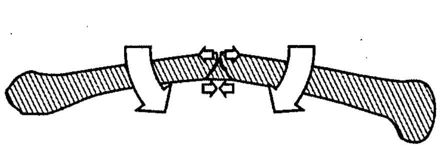

Figure 3. Bending femur fracture.

Injury Criteria

Injury criteria have been defined and used with mixed success in often conflicting ways through the literature. The problems not only reside in a frequent failure to understand the physical basis of the injury event but also in the necessity to apply injury criteria to dissimilar force-time profiles and dissimilar human beings who are experiencing them. Injury by its nature is still a stochastic process even in a relatively uniform population exposed to a reasonably similar stressor. There is no single binary threshold in impact stress below which nobody gets hurt and above which everybody is injured. Instead, there is generally an increasing probability of injury for an increasing level of severity. The problem is how to define severity in a way which will allow different kinds of impacts to be compared in terms of their injury potential.

The approaches that have been used have included terms relating to the motion of the vehicle and terms relating to forces or motions experienced by parts of the occupant. Vehicle-related examples include:

Average Acceleration
Peak Acceleration
Velocity change
Energy change

It should be recognized that velocity change is a measure of momentum change or impulse. Occupant-related examples include similar terms measured for a part of the occupant instead of the vehicle and other terms relevant to the occupant such as:

Belt Loads
Seat Loads
Femur or other long bone Loads or Torques
Spinal Loads, Torques or Shears

Data for these criteria derive from crash tests with instrumented anthropometric manikins. Curves have been developed to try to assess when certain types of injuries are likely to occur for a human on the basis of the instrumentation outputs from the manikins. Neither the curves nor the instrumentation cover all combinations of stresses at all potential injury locations. Moreover, humans differ from manikins in their characteristics and their dynamic response.

Various severity indices have been used to assess the comparative severity of dissimilar pulse shapes by manipulating acceleration-time profiles using various integration and weighting schemes. The GADD Severity Index (SI) was an early example of this approach with the Head Injury Criterion (HIC) as a more recent example.

Unfortunately, the HIC only addresses translational accelerations and the translational component of rotational acceleration, ignoring rotational acceleration and rotational velocity. The ignored terms have been shown to be significant particularly in the occurrence of diffuse axonal injury. Even more fundamentally, none of the listed indices or terms addresses the causation chain from force to stress to strain to yield point.

Some attempts along this line have been made and have met with some success. The Dynamic Response Index (DRI) is

particularly noteworthy. It defines injury probability for spinal fracture in terms of the maximum strain of a simple viscoelastic model exposed to the vertical acceleration profile of the impact. The success of this approach likely relates to its general correspondence with the physical basis of spinal compression fracture which also is based on strain of a viscoelastic structure. Attempts have been made to generalize the DRI approach to three dimensions and to more generalized injuries. Other strain-based approaches have been employed with varying success for the head and chest.

More complex geometric modelling approaches have been developed to attempt to recreate body segment motions and compute internal stresses. While some of these have been useful in understanding body motion, they have not fulfilled the overly optimistic expectations of some for a fully validated means of comprehensively assessing internal stresses, strains, and injury likelihood.

In light of the deficiencies, injury criteria must be applied cautiously in assessing injury potential of a given crash. Dynamic testing with adequately instrumented manikins can, however, demonstrate gross occupant kinematic tendencies and highlight the applied stresses of greatest potential concern. One can also arrive at estimates of how these stresses may be affected by protective interventions.

PREVENTING IMPACT INJURY

Force and Stress Management

Since injury is simply strain beyond the yield point, the prevention of injury reduces to the problem of managing strain and limiting it to the recoverable portion of the stress-strain curve. The way you do that is to limit stress and the way that is done is to limit the force application that produces it and/or apply the force over a larger or more tolerant portion of the body.

Unfortunately, misunderstandings of the physical basis of impact injury have produced some cloudy thinking in this area, particularly with regard to energy absorption. Many seem to think that energy is almost like some kind of fluid that can be transferred around in an impact, concentrated in one place, or sucked up and absorbed so that occupants in a crash vehicle don't get it transferred to them. It isn't so. An occupant of a crashing vehicle, as viewed from a ground reference, has translational kinetic energy of $1/2\ mv^2$ before the crash and zero when the crash is over. His energy must change, and it doesn't change by getting absorbed like water in a sponge. To change the energy of an occupant you must change the velocity, because you can't do much about the 1/2 or the m in the energy term. The only way to change the velocity is to produce an acceleration since $v = a \cdot t$. The only way to produce an acceleration is to apply a force since $F = m \cdot a$. So you change the occupant's energy by applying force. You can't "absorb" it somewhere else or in some other way. The problem of impact protection can be viewed as the problem of rapidly applying substantial force to the body in as benign a way as possible. The management problem in crash survivability is fundamentally one of managing force and the resulting stresses rather than managing energy since you can only "manage" energy by applying force.

But what, then, is all this attention to energy absorption? Energy absorbed is simply work done on an object that doesn't come back in the form of elastic recoil. Crushed metal structure is an example of energy absorption. It has two benefits during an impact. The first benefit is that absorbed energy decreases the total energy change of the impact by decreasing the required velocity change to a minimum. In other words, it doesn't eliminate the "stop" in a crash, but it can decrease the "bounce back". This can have great benefit for the occupant who might not have stopped before he hits a part of the vehicle that is already bouncing back. Such a collision could occur at a velocity greater than the crash velocity. Perfect energy absorption reduces the required velocity change to that of the crash, which in turn reduces the required force during the available distance or time.

The second benefit of energy absorption is that it can allow longer stopping distances and times, reducing the required stopping forces. A very rigid vehicle hitting a barrier stops very quickly with very large accelerations and forces over very short times. A more crushable vehicle hitting the same barrier stops less quickly with smaller accelerations and forces over longer times. The perceptive reader will note that this benefit is actually related more to lower stiffness than to energy absorption since the same benefit would accrue even if the crush had a complete elastic rebound and no energy was absorbed. From a practical standpoint however, very stiff vehicles tend to be more elastic while more crushable vehicles tend to be less elastic and "absorb" more energy. Increased stopping distances and times from deformable structures is therefore a benefit that is reasonably related to the process of energy absorption.

The techniques of managing force in an impact include increasing the stopping time and distance by employing suitable stiffness for the vehicle structure and minimizing elasticity or rebound to decrease the required velocity change. The critical problem is to define what stiffness is most suitable. For a vehicle of given weight, the optimum stiffness depends on how much crush space you can afford and how severe the impact is going to be. The optimum stiffness for one impact severity will not be optimum for another. The ideal situation in a crash is to use up all of the available crush space or stopping distance just as you come to a stop. If you come to a stop without using up all the potential stopping distance, you have been applying more stopping force than you absolutely had to because the stiffness was too high. If you haven't come to a stop when you run out of stopping distance, you "bottom out" and experience very high accelerations and forces at the end because the stiffness was too low.

Unfortunately, you can't have a different vehicle design for each crash, even though some exotic adaptive techniques may eventually prove practical. The basic current approach is to optimize the stiffness - crush space design around some impact severity level which is reasonably likely to occur and where there is significant risk of injury or death. This is done with the recognition that the stiffness will be too high at lower severity levels where injury is less likely anyway. It is also recognized that the stiffness will be too low at higher severity levels where survival is less likely anyway. The chosen design represents a compromise which attempts to provide the most realized benefits over the expected range of crashes, knowing that the design is not likely to be the absolute optimum for any given crash.

Occupant-Oriented Protection

Thus far we have addressed crash survivability techniques relating to the management of forces and accelerations at the center of mass of the crashing vehicle. These accelerations will generally be different from those experienced by some body part of an occupant. The accelerations would only be the same if all parts of the occupant were perfectly coupled to the vehicle at the center of mass. This brings us to another compromise. Perfect coupling to the vehicle allows optimum benefits to accrue from vehicle crush during a significant impact but it is extremely uncomfortable during normal operation. Vibrations of modest amplitude can be tolerated better if occupants are somewhat uncoupled from the vehicle through the use of cushioning for example. Restraints also must allow some room for required motion, particularly for the head and extremities. Occupant decoupling from the vehicle means that, during an impact, the vehicle begins stopping before the occupant, ultimately resulting in shorter occupant stopping times or distances and higher occupant accelerations and forces. The compromise is between some decoupling for normal operation while preserving reasonable coupling for impact protection. Again, some adaptive techniques like belt pretensioners may improve coupling but benefits are likely to accrue only for certain impacts.

Occupant coupling is generally provided with restraint systems. Restraints bring their own set of protection issues, some of which are in conflict with one another. Restraint elasticity may counter some of the energy absorption benefits of inelastic vehicle crush by increasing the occupant's velocity change. At the same time, however, the elasticity of the restraint may allow longer stopping distances and times and lower the peak forces and accelerations. This in turn may promote contacts between some occupant part and internal or external structures which could constitute extremely short duration impacts with high forces and accelerations and lots of bounce.

In general, there will be a different acceleration-time profile for each part of the occupant's body, none of which may duplicate the acceleration time profile for the vehicle center of gravity. Despite all these differences, it is still usually helpful to describe a vehicle impact for comparative purposes, in terms of the acceleration profile for the vehicle structure at or near the occupant's position. We just have to remember that such a profile does not characterize the proximate stresses for a particular body part.

A further complication relates to occupant size. The population of potential occupants includes a wide range of anthropometric dimensions which may significantly alter the impact for all or portions of the body. For high performance aircraft, the severity of this complication has increased in some countries with the inclusion of female aircrew. The problem does not only relate to issues such as flail envelopes, tissue strength, and load variations for given acceleration profiles. In some cases, the imposed acceleration profiles may change as in the case of ejection seats with fixed thrust occupied by different masses. Restraint fit and function issues are also present in such areas as belt and harness angles and chosen seat positions affecting proximity to structure.

The protection strategy is typically to accommodate the broad range of potential occupant sizes and weights with provisions for excluding outliers who just don't fit. The exclusion strategy is usually more difficult in civilian vehicles than in military combat aircraft. Critical dimensions are sized around those who challenge them most. As an example, if a horizontal angle shoulder harness is defined for the tallest practical mid-shoulder sitting height, the angle for the shortest occupant is then assessed. If the range is too great to allow the required coupling, adjustable anchors or a "Just don't fit" category becomes necessary. Adjustable anchors also imply the potential for maladjustment. Care should be taken in analyzing crash injury in occupants of unusual size, since the urge to implicate mis-fitted protective equipment must be balanced by the recognition of the needs of occupants of more typical size and those at the other extreme.

Two other occupant-oriented approaches deserve mention. One is the range of techniques used to limit force and increase stopping distance within the vehicle. The use of stroking seats for helicopter crashes is perhaps the best example. Such seats may be designed to displace at a given applied force, with the seat bottom displacing downward with respect to the floor when more than that force would be required to prevent it. This is a force limiter and it defines the maximum upward acceleration that can be placed on a mass supported by the seat. It is clear that a smaller occupant will get a larger acceleration than a larger occupant exposed to the same force. A larger occupant exposed to a severe impact will stroke the seat more than a smaller occupant. Some systems even allow the occupant weight to be manually set or automatically sensed and adjusted for, at the risk of mis-adjustment and increased complexity. Stroking seats are often called energy-absorbing seats because they have no appreciable elastic rebound, but their role is really to provide force limiting and increased stopping distance for certain combinations of occupant weight and impact severity. If the design force is inadequate to stop the occupant in the available stroke distance, a relative velocity will exist between occupant and floor at the bottom of the stroke which must be rapidly stopped by large accelerations and forces, potentially worse than if the occupant had been in a non-stroking seat from the start. This problem is encountered with heavier occupants and/or more severe crashes. When encountering a fully stroked seat in a crash, the bottom-out velocity may be estimated using the energy equations if the crash velocity change component along the stroke direction and the effective occupant mass acting against the seat bottom can be estimated. Care should be taken in evaluating the significance of the stroke distance for crashes in which the forces are not consistently in reasonable alignment with the stroking direction.

The other occupant-related issue is that of padding. Padding may be vehicle-mounted as on a headrest or occupant-mounted as in a helmet liner. Padding serves three primary functions. First, it may increase the area of force application in an impact which lowers the locally applied stress. This may reduce skull fracture likelihood without meaningfully altering brain injury likelihood. Secondly, padding increases the stopping distance which can lower the magnitude of the applied peak force. Finally, if the deformed padding does not rebound elastically, the padding may serve to absorb energy and decrease velocity change, but only to the extent that the unpadded impact would have had rebound.

The performance of padding varies with the contact velocity, the required velocity change, the mass and visco-elastic

characteristics of the impacting object, and the thickness and viscoelastic characteristics of the pad. The contact velocity and the required velocity change are two different things. If a head is against a pad when a vehicle impact occurs with force along the head to pad direction, the contact velocity would be zero. The further the head starts out from the pad, the greater the contact velocity up to the required velocity change. For a defined impacting object such as a head, a pad with a given thickness would need different viscoelastic characteristics to deliver optimum performance for different contact velocities and required velocity changes. Padding design, therefore, represents yet another compromise in injury protection. Any benefit can be estimated in a given crash by computations using the energy and momentum equations if the pad characteristics are known and estimates are available for contact velocity and required velocity change. Depending on the factors above, padding may be helpful, irrelevant, or harmful in a given impact. Harm would derive from circumstances in which the padding serves to decouple the occupant from the vehicle undergoing an impact. In any event, potential benefits of padding are largely confined to the structure sustaining the proximate impact such as a head for example. Potential for neck injury as a result of head impact is less likely to be beneficially affected by padding but may be made worse if the head "pockets" into the padding while the body continues to move.

Protection at the Margin

The investigation of an aircraft crash in which injury has occurred necessarily turns at some point to the causes of the injury and what can be done to prevent similar injuries in the future. Investigators have often advanced specific, sometimes sweeping recommendations for change in protective modalities which would provide seemingly obvious benefits in the kind of crash being investigated. Sometimes the apparent benefits are not real because they are based on misunderstandings of the physical basis of impact injury as discussed previously. Even when actual benefits would result from the recommended changes however, such recommendations may still be inappropriate if they simultaneously introduce other risks which would outweigh any benefit to be realized. The attendant risks may be more subtle than the benefits. To appreciate the overall result, one must understand both the physical basis of impact injury and the nature of protection at the margin.

No practical impact protection system delivers optimum protection for a given occupant in a given impact. Any real protection system is the result of a host of compromises among factors such as system weight, comfort, mobility and the ranges of occupant position, weight and anthropometric dimensions. In addition, real protection systems must be designed for the entire range of normal and emergency operations and for the entire range of impacts. Some beneficial things you might want to do for one type of impact might be harmful in another and pose additional problems in normal operations.

To approach the truly optimum, an impact protection system might involve a system of restraints with broad coverage areas applied to an occupant completely immersed in a viscous fluid having a density similar to that of their human body. You would need a breathing system. The fluid would be contained in a rigid sphere completely surrounded by a thick crush zone for good measure. You would surely be able to ride out some spectacular impacts, but you would have no visibility, little mobility, and therefore little reason to be there. The weight would be prohibitive. The system would have no operational utility. Designers have appropriately chosen instead to apply basic protection principles in systems which employ reasonable trade-offs among the various, sometimes conflicting design requirements. This necessitates some choices in impact severity levels for which the system will be tailored.

It is difficult to gauge the success of a design since so many factors must be considered and the relative importance of each factor will be perceived differently by different evaluators. It is certainly not reasonable to conclude that the very occurrence of injury in an impact implies a deficiency. Any practical system can be exposed to an impact severity beyond its ability to provide effective protection. More critically to understand, injury will occur even in well-designed systems when exposed to impact severities in the range for which the systems do provide effective protection. This is so because injury is a probabalistic event. An effective protective system may reduce the likelihood of injury for a given impact severity from a high level to a low level. When injury does occur with such a system, the urge to recommend change must be balanced by a sober evaluation of the potential deleterious effects that may be introduced for occupants in other circumstances.

This is particularly true when evaluating unusual or especially severe impacts. Since injury will become increasingly common at the margins of a system's protective capabilities, the urge to recommend change for impacts at these margins becomes greater. The changes, however, generally tend to move the design's optimization point to the more extreme impacts and often degrade protection in the more commonly experienced severity ranges where injury and fatality reduction is most achievable.

Examples abound where well-meaning "improvements" have been incorporated into protective systems only to have the injury and fatality outcomes made worse. This is not to say that current systems cannot be improved. It is to say that the variables in today's systems are sufficiently great that it is difficult to be sure that a proposed modification will represent an overall improvement. Most changes carry with them both benefit and risk.

The thoughtful investigator will assess injury occurrence with reference to its physical basis and in the context of the impact event and the overall performance of the occupant protection systems across the entire range of requirements. This will allow carefully considered contributions to the evolution of improved protection. The easy gains and many harder ones, have already been made.

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THE PHYSICAL BASIS OF IMPACT INJURY AND ITS PREVENTION

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INTRODUCTION

Effective prevention of injury in aircraft crashes and the investigation into injury occurrence in those crashes requires a knowledge of how impact injury occurs and how protective techniques work. This review will examine the physical underpinnings of the art of impact protection as applied to vehicular impacts. The same principles apply to terrestrial vehicles, aircraft, and spacecraft in a wide range of impacts and other sudden accelerations. Because they happen so rapidly, they are sometimes difficult to understand in terms of our slower moving daily experience. Some of the understandings may even be counter-intuitive as a result of the need to observe the event from various frames of reference.

The review must therefore begin with some basic physics and apply those principles to the collision event. Approaches to describing crash motions and crash severity will be outlined before describing how to analyze occupant motions in a crash. The physics of injury will be briefly reviewed and applied in defining injury mechanisms and injury criteria. Finally, general approaches to crash protection will be addressed along with some perspectives on how to analyze and assess the effectiveness of crash protection. Example cases will be presented with the oral presentation to illustrate the application of the principles reviewed in the paper.

The effort to understand crashes, injury, and injury protection at this level will be well-rewarded through the development of improved insight into the process of crash protection in automobiles, aircraft, and other vehicles.

PHYSICAL PRINCIPLES

The Laws Of Motion

We begin our study of impact injury with a brief review of physics since the terms and methods used to study motion are necessary in understanding impacts. Failure to appreciate and rigorously apply the principles of physics has led to many misunderstandings about how impact injuries occur and how they can be meaningfully addressed.

Some definitions may be helpful at the outset. An impact is a short duration force event which typically alters the motion of an object. Force is simply a push or pull. Motion is change of an object's position as measured in some frame or reference. Velocity is the rate change of that position with respect to time. Acceleration is the rate of change of an object's velocity with respect to time. Position, velocity, and acceleration are all vector quantities, meaning they have both a magnitude or size, and a direction.

The first of Newton's Laws of Motion states that an object at rest or in motion will remain so unless acted upon by some force. The second law states that when a force acts on an object, the object is accelerated in a manner which is directly proportional to and in the direction of the net force acting and inversely proportional to the mass of the object. The equation for this law is

$$\mathbf{F} = m \cdot \mathbf{a}$$

Mass can therefore be thought of as the resistance an object has to being moved. Mass is not weight. Weight is rather a force, namely the upward force provided on an object by a scale, for example, to balance the force of gravity acting on an object's mass. Gravity is also a force. In a vacuum at the earth's surface, the force of gravity will produce an acceleration downward of 9.81 meters per second per second (1g) on any unsupported object since the force of gravity is also proportional to the object's mass. The unit of g is a unit of acceleration, not a unit of force. The term g-Forces is a misnomer.

The third law of motion states that, for every action, there is an equal and opposite reaction. In other words, if we bump heads, the force on each head is equal in magnitude but oppositely directed.

The Physics of Collisions

This brings us to collisions. Let's start by considering two perfectly spherical and perfectly rigid balls of equal mass moving through space directly at each other, each with equal but oppositely directed velocity. After they collide, they will be moving directly away from each other, but the rest of the description will have remained the same. In effect, the two balls instantaneously traded velocities at the point of collision. This would be described as an idealized elastic collision.

Two equations can be written to describe this behavior. The first goes by the name of conservation of momentum and uses the quantity mv for momentum which is simply mass times velocity and remains a vector quantity. In our collision,

Paper presented at the AGARD AMP Lecture Series on "Injury Prevention in Aircraft Crashes: Investigative Techniques and Applications", held in Farnborough, UK, 24-25 November 1997, and Madrid, Spain, 1-2 December 1997, and published in LS-208.

$$m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = m_1\mathbf{v}_1' + m_2\mathbf{v}_2'$$

where the primed terms refer to the post-collision values. The second equation is referred to as conservation of energy and uses the quantity $1/2\ mv^2$ for kinetic energy which is simply half the mass times velocity squared and is not a vector quantity. In our collision,

$$\tfrac{1}{2} m_1 v_1^2 + \tfrac{1}{2} m_2 v_2^2 = \tfrac{1}{2} m_1 v_1'^2 + \tfrac{1}{2} m_2 v_2'^2$$

At first glance, it may not seem that the energy equation adds much understanding to the event, but it actually does for several reasons. Some will become apparent as we explore the applicability of these equations to more general classes of collisions. Others are wrapped up in the different ways that momentum and energy undergo changes. Momentum is changed by force acting over time, a quantity known as impulse. Energy is changed by force acting over distance, a quantity known as work. For constant force values, momentum change for an object is force times the time duration over which it acts. Energy change for an object is force times the distance over which it acts.

In our previous collision example, the time duration and distance for the collision forces were infinitesimally small, so the force magnitude was infinitely large. For a slightly more realistic situation, consider balls made of a strange elastic material which pushes back with the same force no matter how deeply you indent it, but it will always rebound completely to its original shape. Now the collision will produce the same post-collision results but the collision will have a real time duration and distance over which the collision forces act. Assume a mass for each ball of 1 kilogram, a velocity for each ball of 1 meter per second and a restoring force for each ball, when indented, of 10 newtons. When the balls collide, they will slow down as they mutually indent each other, coming to a complete stop together at maximum indentation before rebounding back to achieve velocities equal in magnitude to the pre-impact velocities, but oppositely directed.

We can calculate the collision time since we know that momentum change is equal to the impulse:

$$mv = \mathbf{F} \cdot t$$

$$1\ \text{kg} \cdot 1\ \text{m/sec} = 10\ \text{kg-m/sec}^2 \cdot t$$

$$t = 0.1 \text{ second to come to a stop}$$

It will take another 0.1 second to rebound back for a total collision time of 0.2 second.

We can calculate the indentation distance since we know that energy change is equal to the work:

$$\tfrac{1}{2} m\, v^2 = F \cdot x$$

$$\tfrac{1}{2} \cdot 1\ \text{kg} \cdot 1\ \text{m}^2/\text{sec}^2 = 10\text{kg-m/sec}^2 \cdot x$$

$$x = 0.05\text{m or } 5\text{ cm}$$

The two results are consistent since each slowing ball will have an average speed of 0.5 m/sec operating for 0.1 sec during which 0.05 meters of distance would be covered (since distance equals average speed times the time duration).

We can also calculate the acceleration level. Since we know that 1 m/sec of velocity was reduced to zero in 0.1 seconds, the constant acceleration level was

$$(-1.0\text{m/sec})/0.1\text{sec} = -10\ \text{m/sec}^2$$

for the ball with a pre-impact positive velocity. We also know that this constant acceleration of a little more than 1 g acted for a total of 0.2 seconds to build up the same velocity in the other direction. An equal but opposite acceleration acted on the other ball for the same time duration. The total velocity change for one ball would be -2.0 m/sec and +2.0 m/sec for the other.

The impulse for a ball in the collision has a magnitude of 2 newton-sec since it is computed as constant force (10 newtons) times time (0.2 sec) with the direction for the impulse on the other ball being opposite. The energy change for each ball in the collision is $1/2\ mv^2$ or $1/2 \cdot 1\ \text{kg} \cdot (1\ \text{m/sec})^2$ or 0.5 newton-meters to stop it and another 0.5 newton-meters to get it back to 1 m/sec in the opposite direction. The total energy change for each ball is therefore 1 newton-meter. Please note carefully that the energy change for a 2 m/sec velocity change would be

$$\tfrac{1}{2} \cdot 1\text{kg} \cdot (2\ \text{m/sec})^2 = 2 \text{ newton-meters}$$

if the velocity went from 2 m/sec to zero. If you calculated the energy change for a 2 m/sec velocity change from 4 m/sec to 2 m/sec, you would get 6 newton-meters. For a 2 m/sec velocity change from 10 m/sec to 8 m/sec you would find an energy change of 18 newton-meters. Each of those collisions could have the same impulse. The critical observation to make is that energy change ascribed to a collision depends upon your frame of reference. However, an object or person experiencing a collision will "feel" it in only one way. The severity of a collision can be mischaracterized if energy change is utilized from the wrong reference frame.

The most meaningful description of a collision is to describe the acceleration-time profile of a relevant point as measured from a non-accelerated non-rotating reference frame. This profile is often called the crash pulse. Velocity change can then be determined and overall severity assessments made on the basis of the square of the velocity change to avoid the reference frame problem mentioned above. Comparing the severity of two impacts can still be difficult since time durations and acceleration-time profiles can differ in significant ways for impacts with identical velocity changes. We will address some of those difficulties presently.

Thus far, we have addressed simple collisions of elastic balls with constant forces during the collision. Another type of collision could be visualized in which the balls deform but do not rebound. An example would be dropping a lump of soft modelling clay on the floor. These are called inelastic or "hit and stick" collisions. They can be analyzed in the same fashion as the first half of an elastic collision. Conservation of momentum equations still hold. Conservation of energy equations still hold too, but you must account for the work done in deforming the object which is not given back on

rebound. That reduces the velocity change by 50% and reduces the energy change by as much as 75% depending on your reference frame. It also reduces the time duration by 50% for colliding objects of the same stiffness.

It is also helpful to consider a different kind of deforming ball in a collision with an increasing restoring force the more you indent it. Suppose you had one which produced an acceleration-time profile that looked like an isosceles triangle for the elastic case. It can be shown that such objects in our earlier collision scenario would have a peak acceleration at the top of the triangle which would be exactly twice the value of the constant force collision when the velocity changes and time durations are the same. The peak acceleration for the inelastic triangular pulse is also twice the value for the constant force case. This allows us to use the fairly simple constant acceleration calculations and then substitute the triangular pulse at twice the peak acceleration when we are done. This turns out to be much closer to the behavior of real crashes.

Another way to adapt our calculations to real crashes is to observe that a collision into a barrier, like the ground, can be treated similarly, usually neglecting gravity since it is typically a minor consideration compared to crash forces. Our equations then reduce to an impulse equation where the momentum change is equal to the area under the force-time curve and an energy equation where the energy change, including the work done in deforming structure, is equal to the area under the force-distance curve.

Real collisions fall somewhere between the elastic and inelastic case, described by a term called the coefficient of restitution. If there is rebound from a collision with a fixed barrier with equal and opposite velocity to the approach velocity, then the coefficient of restitution is one. If there is no rebound, the coefficient of restitution is zero. Rebound with half the magnitude of the approach velocity implies a coefficient of restitution of one half.

We now have enough tools to handle a lot of simple crashes, as long as there isn't much rotation. Rotation brings in a significant added complexity since there is a whole parallel set of considerations for rotation that are analogous to what we have just described for translational motion. You can describe angular position or orientation just as you can describe translational position. Angles are used for the description instead of distance, but you still need a frame of reference, ultimately one that can be considered as non-rotating. You then have angular velocity, angular acceleration, angular momentum, angular impulse, angular force (torque) and angular energy. The angular analog to mass is the moment of inertia which is an object's resistance to rotational acceleration. It is typically different depending on which axis you try to rotate it about.

Many collisions and crashes involve substantial rotations which can significantly effect vehicle motions, occupant motions, and injury outcomes. We will address some of those complexities as we proceed without invoking the full translational and angular equations necessary for a comprehensive reconstruction. Suffice it to say here that simple crash force calculations for a single impact crash can often proceed on the basis of computations for the center of gravity motion of the vehicle, with angular motion often required to be taken into account for multiple impact crashes.

The outline of the basic approach is as shown below for a crash as shown in Figure 1, where the flight path angle is typically different from the aircraft angle, where the airspeed is known, and where the aircraft slides to rest after leaving an impact ground scar. First compute the horizontal velocity after the ground scar as $v'_{horiz} = [2\ \mu g d_s]^{1/2}$ where μ is the coefficient of friction during the slide distance and g is 9.81 m/sec^2 (the acceleration produced by gravity). The coefficient of friction can be estimated, or assessed from experimental data. A value of 0.3 - 0.5 is not atypical for aircraft sliding on ground without plowing. We know that the aircraft's vertical velocity must go from its initial value v_{vert} to zero in the distance.

$$d_{vert} = d_{crush} + d_{scar\ depth}$$

We also know that the aircraft's horizontal velocity must go from its initial value v_{horiz} to v'_{horiz} in the distance of the ground scar length (d_{horiz}). Measurements on the aircraft and the ground scar provide these data. We then compute

$$v_{horiz} = v_{initial} \cos\text{(Flight path angle)}$$
$$v_{vert} = v_{initial} \sin\text{(Flight path angle)}$$

We then can solve for average or constant force accelerations with respect to the earth.

$$(a_{horiz})_{AVG} = (v_{horiz}^2 - v'^2_{horiz}) / 2gd_{horiz}$$

$$(a_{vert})_{AVG} = (v_{vert}^2)/2gd_{vert}$$

Pulse times can then be computed.

$$\Delta t_{horiz} = (v_{horiz} - v'_{horiz})/a_{horiz}$$

$$\Delta t_{vert} = v_{vert}/a_{vert}$$

This implies constant acceleration or rectangular pulses. Triangular pulses would have twice these values at peak. For a crash with no rotation and no roll or yaw, the accelerations at each point in time can be easily resolved into aircraft axes using the pitch attitude at impact (θ) assessed by observing the aircraft crush.

$$a_{forward} = a_{horiz} \cos\theta + a_{vert} \sin\theta$$
$$a_{vertical} = -a_{horiz} \sin\theta + a_{vert} \cos\theta$$

The values must be computed at each time step. With roll and yaw involved, more complex matrix transformations are required. For many events, however, the calculation methodology outlined here can provide useful first estimates of the center of mass accelerations.

An important final observation is in order here. The preceding calculations and most detailed accident reconstructions relate specifically to the aircraft center of mass. They do not define the aircraft accelerations at all points. Reconsider our deforming ball collisions. They were better behaved than the imaginary rigid ball collisions where accelerations were infinite. The center of mass of the deforming ball was able to change velocity slower while the

zone of deformation deformed. That doesn't apply to a part of the ball in the zone of deformation. In fact, the point of the ball that first contacts a barrier (or another similar ball) still gets a nearly infinite acceleration of nearly zero duration. This is yet another reason why real impacts of aircraft and people are so difficult to characterize.

The Principles of Occupant Kinematics

The calculations of collision physics are principally based on the second and third laws of motion. Kinematics is based principally on the first law. Occupant kinematics relates to the motion of an occupant with respect to his vehicle without regard to the forces that create the motion. This is precisely because forces on the occupant typically don't create the displacements of occupants with respect to aircraft during crashes. Instead, the displacements are produced by crash forces on the aircraft while the occupant continues to obey Newton's first law.

In crash test films made with on-board cameras, it appears that occupants may be suddenly "thrown" forward. In reality, the pre-crash forward motion of the aircraft is rapidly stopped because it hits the ground. The camera, which is screwed to the aircraft, also stops rapidly. The occupant, who is not screwed to the aircraft, continues to move because he hasn't been notified of the crash yet. He displaces with respect to the aircraft and the camera not because he is "thrown" forward. If anything the aircraft and camera are being "thrown" rearward. The forces on an occupant, in this setting of a frontal barrier crash are actually rearward forces from restraints, angled seat bottoms, and front structures. They just occur a bit later than the crash forces on the vehicle. It will be helpful in understanding injury protection to rigorously track the directions and sources of the forces being applied.

Occupant kinematics is helpful in assessing injury and its prevention even though forces are not directly taken into account. Fundamentally the computation of occupant kinematics involves assessing two trajectories or motion paths. The first is the trajectory that the occupant would follow if the crash had not occurred. The second is the trajectory that his surroundings follow as a result of the crash. If a forward moving vehicle strikes a barrier, the occupant continues to move forward with respect to the slowing aircraft. The timing and extent of that motion can be assessed if you have reasonable estimates of the acceleration-time profiles of the occupant's surroundings. If a falling helicopter strikes the ground, the occupant continues to move downward with respect to the slowing aircraft. From these types of observations, people have sometimes been lulled into the mistaken notion that occupants simply move toward the point of impact. That is not true. Occupants obey Newton's first law. Consider an unrestrained occupant in a taxiing aircraft which strikes a tree with its right wing. Comparison of occupant and aircraft trajectories will reveal that the occupant moves forward and increasingly to the left with a respect to the aircraft as the aircraft is slowed and rotated clockwise. The occupant's trajectory with respect to the aircraft will actually be a curved path, forward and curving to the left. He certainly does not go toward the right wing point of impact!

Occupant kinematics in real crashes depend on the degree of coupling to the vehicle. An uncoupled occupant such as a person standing on the hood of an automobile striking an embankment will follow an entirely independent trajectory from that of his vehicle. An occupant perfectly restrained to his vehicle in a form-fitting, rigid cocoon will be constrained to follow his vehicle's trajectory, but his interaction with his cocoon will be that which will be dictated by his kinematic tendencies as he "tries" to maintain his current motion path at each point in time. Assessing the difference between the two trajectories and factoring in knowledge of constraints will allow meaningful evaluation of the direction, severity, and character of the occupant's interactions with his environment.

An example of this approach may be seen in the assessment of a head impact into aircraft structure during a helicopter crash. Suppose investigation showed a clear helmet imprint on a piece of structure and matching damage to the helmet. Using the accident reconstruction acceleration-time profiles relevant to that point of structure, the range of potential pre-impact head positions could be computed to allow the unconstrained head to reach that point of the structure and a range of impact velocities could be computed for pre-impact head positions within the possible range. Comparing the actual head impact severity with the computed range of

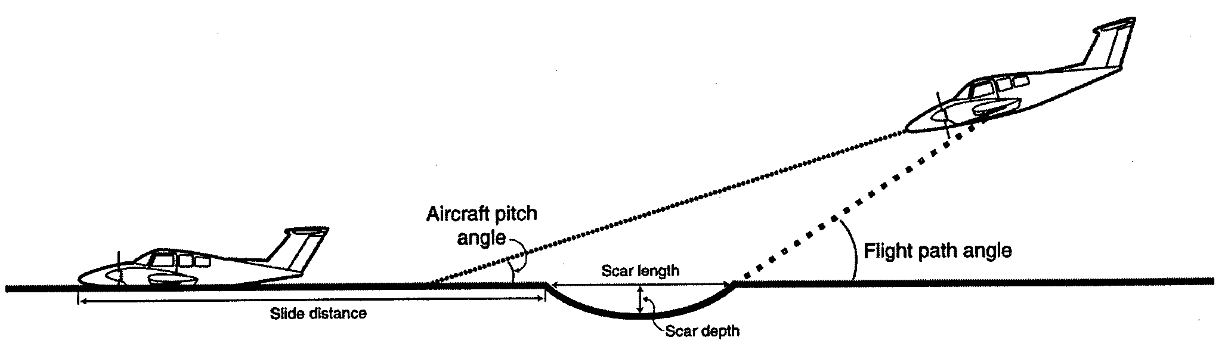

Figure 1. Aircraft pitch angle and flight path angle relating to a ground collision. Adapted from M.W. Dobbs.

velocities could allow an estimate of the occupant's head position immediately pre-impact.

Even when unconstrained motion of an occupant or body part is an unwarranted assumption, kinematic computations for unconstrained bodies can lead to useful assessments of the timing and character of occupant interactions with restraints, seats, or other structures. The method is relatively simple. One must simply integrate the acceleration-time curves for the relevant location or locations in the aircraft. This results in velocity-time curves for those points. These are then integrated again to produce displacement-time curves. At the points in time where displacements are sufficient to allow occupant contacts, the velocity curves can be consulted to assess maximum relative velocities for those contacts.

It may also be useful to employ one of several available computer simulations to assist in kinematic assessments. Caution is in order however since simulations, and indeed the kinds of calculations discussed here can create a false sense of precision when that sense is clearly unwarranted. No computer simulation of kinematics has been validated for all the applications which well-meaning people may dream up for it. Nor will such programs detect for you when a misapplication is being attempted. Errors in assumptions input data or reference frames may still lead to deceptively real-looking results. In the effort to understand a phenomenon as counter-intuitive as impact can be, there is no substitute for careful "Reality Checking" through the use of independent lines of analysis.

We have now discussed the basic tools used in understanding the impact event. It remains now to discuss their application in the assessment of injury causation and prevention.

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APPLICATIONS OF PHYSICAL ANALYSIS AND CRASH SURVIVABILITY

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INTRODUCTION

An aircraft accident is always an emotional event that triggers a flurry of activity, particularly if fatalities are involved. Rescuers, damage control crews, search and rescue teams, MEDEVAC teams, and support staff each play a well rehearsed role in activities surrounding the event. Every accident is unique, with its own set of circumstances, surroundings, mysteries and dangers. Initial confusion is always present. But amidst the wreckage, log of events, communication tapes, eye witness accounts, mission briefing, technical manuals, personal interviews and pathology lie important clues that, properly organized and understood, will indicate the cause and the consequences of the accident.

The questions confronting an accident investigation board can vary, but usually involve two issues. The first centers on the cause of the accident. Explaining the cause is fundamental to future prevention of similar accidents. The task of making 'sense' from 'nonsense' can be awesome. An investigating team is usually confronted with a confused abundance of physical and human evidence, and an organized approach to information collection and analysis is needed to succeed.

The second issue centers on the consequence, specifically the question of injury outcome of aircraft occupants. Outcome is related to the crashworthiness of the aircraft. Crashworthiness is the ability of an aircraft to provide protection during impact conditions. While great effort has gone into designing crashworthiness into some modern aircraft, others have received little design crash protection. Injury outcome correlates directly with the success of the crashworthy design. Many of the principles behind a successful design were discussed in the previous two lectures. These principles need to be understood by the investigating medical officer.

The approach to assessing injury outcome was alluded to previously and is used by many medical crash investigators. The "CREEP" acronym is a reference tool that defines this approach. The CREEP approach systematically analyzes the container, restraint system, environment, energy absorption features, and post-impact factors in order to determine injury outcome. This determination will be the medical officer's most important contribution to the accident board. In order to effectively assess CREEP factors, an understanding of the impact forces acting on the aircraft and occupants must be obtained.

CRASH VECTOR ANALYSIS

As described in the previous lecture, when an aircraft strikes the ground during an accident, the aircraft experiences an opposing force of very short duration (impact). This force compels the aircraft to change its velocity, reducing the initial speed to a final speed that will eventually be zero. The peak magnitude of this opposing force will depend on the length of time the force can act. If the time available is short, a higher peak force will result compared to when time available is longer. For example, a pilot who lands an aircraft and decelerates with full braking to a stop will feel a relatively high forward force. Alternatively, if the pilot lands and coasts to a stop without using brakes, a much lesser force will be felt. The final result is the same - the aircraft stops. The difference is the length of time the decelerating force is applied and hence, the peak magnitude of the force.

During an aircraft impact, "work" is applied by the earth (or ground structures) to the aircraft that diminishes the kinetic energy of the aircraft to zero. If it is assumed that the decelerating force is constant over the distance of work (which it is not), it is possible to picture the material response of the aircraft to the impact. Aircraft materials respond mechanically to the forces in a manner that depends on magnitude and direction of the force. Individual aircraft structures can distort short of failure (ie. a bent landing gear), to failure (ie. wing torn off), or well past failure to the point of total structural disruption/disintegration. With total structure failure, flammable fluids can be liberated, misted and ignited. The final resting condition of the aircraft depends on the material response to all of the forces acting on the aircraft during the impact.

Another way of thinking of this force is by considering acceleration. Force and acceleration vary

Paper presented at the AGARD AMP Lecture Series on "Injury Prevention in Aircraft Crashes: Investigative Techniques and Applications", held in Farnborough, UK, 24-25 November 1997, and Madrid, Spain, 1-2 December 1997, and published in LS-208.

directly when mass is constant (a reasonable assumption most of the time). Therefore, we can think of acceleration as directly related to force. Acceleration is often expressed as a ratio to the acceleration of gravity ("G"). G is commonly used in describing human tolerance.

Fundamental to the assessment of injury outcome is the calculation of magnitude and direction of the G experienced by the human occupant at impact. Knowing G at impact, a comparison can be made with known human tolerance data in order to assess the severity of whole body deceleration.

CRASH LOAD CALCULATIONS

While the investigating medical officer may not be expected to calculate the direction and magnitude of crash forces (or impact G), an appreciation of the process is important. To calculate these forces, it is necessary to know:

1. Initial and end velocities of each impact (primary and secondary).

2. Vertical stopping distances (depth of marks/gouges in the earth, extent of vertical damage to the aircraft, stroking of energy attenuation devices such as oleo struts and seats).

3. Horizontal stopping distances (length of marks/gouges in the earth, extent of airframe horizontal damage, rearward displacement of aircraft components).

4. An estimate of the shape of the deceleration force-time pulse specific to the accident.

PROBLEM SOLVING

The following approach to calculating crash force vectors is suggested:

1. Ensure consistency of units.

2. Draw a large diagram and label every known distance, velocity, and angle including terrain angle and aircraft attitude on impact.

3. Estimate the acceleration pulse or pulse possibilities and the final velocity.

4. Resolve the vertical and horizontal component velocities with respect to the earth.

5. Calculate vertical and horizontal accelerations (using the equations appropriate to the estimated crash pulses (Annex A).

6. Resolve the resultant acceleration vector with respect to the aircraft from component vertical and horizontal acceleration with respect to the earth.

7. Calculate the time of the acceleration pulse (using equations appropriate to the estimated pulse (Annex A)).

8. Estimate severity in terms of whole body acceleration by using human tolerance charts.

The central questions that these estimates try to answer are: 1) What was the expectation of survival in the crash? 2) If the answer is "unlikely", then detailed assessment of crash protection may not be a priority of the investigation. 3) If the answer is "likely", and the aircraft occupants were seriously or fatally injured, then how were the injuries caused? Assessment using the CREEP reference tool should then become a high priority of the investigation.

CRASH SURVIVABILITY

CREEP is a reference tool that describes an approach to survivability analysis. CREEP stands for:

C = Container

R = Restraints

E = Environment

E = Energy absorption

P = Postcrash factors.

THE CONTAINER

The term container describes the compartment/cockpit space that surrounds the aircraft occupant. A perfect container would completely protect occupants from incursions of outside materials/debris during the impact. During helicopter crashes, rotor blades may penetrate the aircraft container and cause injuries. Deformations of the container that reduce survivable space can cause injury and death. Restitution of container structures following impact can lead to the mistaken observation that survivable space was not compromised. Penetrating bird strikes are a relatively common form of container compromise that causes accidents.

THE RESTRAINT SYSTEM

A frequently employed restraint system has '5-points', or 5 points of attachment with a waist-level release device. The 5-point system consists of two shoulder straps, a waist strap that fits securely over the anterior superior iliac spines, and a central tie-down strap that holds the waist strap in place during deceleration. However, 4-point (waist and shoulder straps), and 2-point (waist strap only) systems are also used.

Evaluation of injury outcome should include understanding the interaction of the occupant with the

aircraft through the restraint system. Injuries should be evaluated with respect to forces applied by restraining systems. Any accident investigation must include a comprehensive evaluation of the complete restraint system.

THE ENVIRONMENT

In the presence of tolerable whole body decelerating forces, a well restrained occupant in a perfectly preserved container can nevertheless be seriously injured by environmental hazards. The impact environment contains forces sufficient to decelerate an occupant from the initial aircraft velocity to a final velocity. These forces will apply over the whole body, and also the segments of the body with various degrees of restraint. The effect of these forces on body segments will vary, as will injury patterns. Thus, a chest decelerating into a restraint harness will experience a different injury force than a head decelerating into a control surface. During impact, poorly attached bulkhead-mounted equipment such as radar units or fire extinguishers can become detached and cause injury.

ENERGY ABSORPTION

By absorbing energy during impact, the aircraft effectively increases the distance (and time) through which the occupant decelerates, thereby decreasing the peak crash force experienced. If the aircraft is designed to be rigid, deceleration of the occupant seat will closely match deceleration of the aircraft and little energy attenuation will occur. If the aircraft crushes in a controlled manner, acceleration distance is increased and crash force decreases. Honeycomb construction, stroking seats, helmets, collapsible landing gear and landing strut systems are a few design features that can facilitate energy absorption. Landing gear that can accommodate a sink rate of 35 feet per second during stroke are present in some aircraft.

POSTCRASH FACTORS

The assessment of postcrash factors is very broad, encompassing all of the hazards attendant at a crash and survival site. There are myriad postcrash factors influencing survivability. These hazards can include physical obstacles that impede escape, such as poorly designed and placed seating arrangements, or difficult-to-open emergency exits. Fire byproducts can poison the cabin atmosphere, quickly incapacitating occupants. Unstowed baggage or a direct fire threat can cut off escape. Survival against the elements in remote locations is a very important concern that has prompted much research into methods of enhancing warm and cold survival on land and sea. The role of life support equipment, including the ejection seat, water survival gear, and environmental clothing needs critical assessment. More than one aviator has survived the crash, only to drown or freeze because of inadequate protective equipment. The role of emergency rescuers needs to be assessed - did the emergency plan and execution enhance or detract from survivability? Was training a factor? Did communications, or lack of communications, contribute to the problem? Were proper medical decisions made?

PUTTING IT TOGETHER

The bottom line of any medical investigation of an aircraft accident is determination of the cause and consequence. Assessment of the consequence involves the central issue of injury outcome. Assessment of outcome can be conducted systematically by first estimating the crash forces that would have been experienced by each of the occupants. An understanding of these forces within the context of the occupant's seated position and activities should allow a full assessment of outcome utilizing the CREEP reference tool. In the presence of "likely" survivable decelerating forces, any injury or death should be explainable in terms of some combination of container, restraint system, environment, energy absorption, or post-crash factors. Future designs that exploit the lessons learned from systematic analysis will lead to enhanced crashworthiness and improved survivability.

ACKNOWLEDGEMENT

Many of the ideas contained in this paper were influenced by United States Navy and Canadian Forces instruction which was, in turn, influenced by the instruction of others engaged in this field. The important contributions of the many people who have contributed to the process of aircraft accident investigation is acknowledged.

ANNEX A

ACCELERATION PULSE SHAPES AND EQUATIONS (WITH RESPECT TO THE EARTH)

Definition:

V_o - initial velocity in feet per second
V_f - final velocity in feet per second
t - pulse duration in seconds
G - acceleration in Gs
S - acceleration distance in feet

I. Rectangular Pulse - Constant Deceleration:

$$\textit{Deceleration Force}: G = \frac{V_o^2 - V_f^2}{64.4S}$$

$$\textit{Pulse Duration}: t = \frac{V_o - V_f}{32.2G}$$

II. Triangular Pulses - Constantly Changing Deceleration:
Case A - Increasing Deceleration:

$$\textit{Decelertaion Force}: G = \frac{4V_o^2 - 2V_oV_f - 2V_f^2}{96.6S}$$

$$\textit{Pulse Duration}: t = \frac{2(V_o - V_f)}{32.2G}$$

Case B - Decreasing Deceleration:

$$\textit{Deceleration Force}: G = \frac{2V_o^2 + 2V_oV_f - 4V_f^2}{96.6S}$$

$$\textit{Pulse Duration}: t = \frac{2(V_o - V_f)}{32.2G}$$

Case C - Increasing and Decreasing Deceleration:

$$\textit{Deceleration Force}: G = \frac{V_o^2 - V_f^2}{32.2G}$$

$$\textit{Pulse Duration}: t = \frac{2(V_o - V_f)}{32.2G}$$

III. Half-sine Pulse - Constantly Changing Rate of Deceleration:

$$\textit{Deceleration Force}: G = \frac{.7854(V_o^2 - V_f^2)}{32.2S}$$

$$\textit{Pulse Duration}: t = \frac{1.57(V_o - V_f)}{32.2G}$$

AVIATION PATHOLOGY

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INTRODUCTION

Aircraft crashes are generally predictable in type and frequency. Different types of aircraft have different types of crashes. Similarly, occupant injuries follow generally predictable patterns, and themselves often consist of patterned abrasions and contusions reflecting portions of the aircraft structure. The role of the medical investigator and/or pathologist includes documentation and interpretation of these injuries to determine how the injuries occurred so that they may be minimised or prevented. The pathologist's documentation and interpretation of injuries, together with manifestations of natural disease processes, provides the core of the Human Factors data for analysis. As few pathologists are familiar with aircraft crash injuries, their interpretation of the injury patterns may be incorrect, which may significantly compromise the investigation.

Although the general aviation accident rate has steadily declined, the fatality rate remains high. A fatal outcome is twice as likely as a serious injury, in contrast to automobile crashes, wherein there is a tenfold greater incidence of serious injury over death. In commercial (passenger) aviation, the problem of escape from the crashed aircraft remains high. An accident involving in-flight breakup or a high-angle, high-speed impact into ground is clearly non-survivable. But such crashes are uncommon. The majority of airline crashes occur during the take-off and landing phases of flight. Speed is relatively low, and impact angles shallow. The decelerative forces on the passengers are, therefore, often survivable. It is unfortunately common for the passengers to survive the impact, but die in the post-crash fire.

PATTERNS OF INJURY

Different types of aircraft have different flight operations, and, therefore, tend to crash in different, generally predictable ways. Their occupants will tend to have similar patterns of injury. The general concepts of crash worthiness have been most extensively incorporated in the design and construction of aerial applicator aircraft built since the early 1960's. These crash safety design features include: Aft location of the cockpit to provide maximum crushable space and allow for rearward displacement of the engine without intrusion into the cockpit, design of the cockpit as the strongest part of the airplane, incorporating a keel beneath the fuselage to allow the airplane to slide along the ground, placing fuel tanks away from the cockpit and engine to reduce the possibility of fire, and incorporating strong seat belt and restraint systems.

Light Aircraft

These airplanes comprise the vast majority of the general aviation fleet. Most light airplanes weigh between 900 and 2000 kg, although they may weigh as much as 5500 kg. Typically they are powered by one or more reciprocating engines. Most accommodate two to six people. Usually they are equipped with two sets of flight controls. Take-off and landing speeds are approximately 100 - 150 km/h. Most cruise between 150 and 300 km/h.

The majority of accidents occur during take-off and landing at relatively low speed. Fatal injuries are often qualitatively similar to those seen in high speed automobile accidents. Angles of ground impact are commonly shallow, so that the aircraft may bounce or slide along the ground, reducing peak decelerative loads.

During the crash sequence the victims are seated and wearing either lap belts or lap belt-shoulder harness combinations. Injuries of head, neck, and upper torso are related to the degree of upper torso flailing and structural deformation of the passenger compartment. Flailing injuries of extremities are common. Legs may be injured by upward collapse of the passenger compartment floor.

Occasionally a light airplane experiences a major structural failure in flight, or a mid-air collision. Crash forces in such accidents may approximate those which occur on ground impact from free-fall (approximately 36 m/s).

Aviation fuel is readily volatilized during a crash, and there are many possible ignition sources; post-crash fires are common. Thermal damage complicates victim identification and assessment of mechanical injuries. The pathologist must differentiate pre-mortem from post-mortem burns and determine the relative importance of thermal-toxic versus mechanical injuries. The possibility of in-flight fire with incapacitation having occurred prior to ground impact must also be considered.

Rotary Wing Aircraft (Helicopters)

Most helicopters have a single rotor with two

Paper presented at the AGARD AMP Lecture Series on "Injury Prevention in Aircraft Crashes: Investigative Techniques and Applications", held in Farnborough, UK, 24-25 November 1997, and Madrid, Spain, 1-2 December 1997, and published in LS-208.

or more blades. Some of the larger or special purpose helicopters have two separate rotors. Power is provided by one or two engines which maybe of either reciprocating or turbine type. Forward cruising speeds are generally between 130 to 300 km/h.

Safety design considerations are complicated by the necessity of positioning the large and rapidly revolving rotor blades over the fuselage, and the need for locating heavy engines, gear boxes, fuel tanks, and occupants near the center of gravity beneath the gyroscope-like rotor. Weight limitations restrict the degree of structural stiffening of occupant areas. The need for unobstructed forward and downward vision places the pilot(s) in the nose of the aircraft where little aircraft structure is available to absorb crash forces. Helicopter crash forces are primarily in the vertical axis.

There are few injuries sufficiently distinctive to be called characteristic of a helicopter accident as opposed a fixed-wing aircraft mishap. An unbalanced rotor, usually the result of a blade striking trees or the ground and losing the tip, will cause the rotor blades to flail wildly. The rotor blades will often strike the fuselage and cockpit, and may sever the tail boom, disrupt fuel cells, and/or cause decapitation, amputations, or transections of the occupants, something rarely seen in fixed-wing aircraft crashes. Multiple fatal injuries are primarily caused by vertical crash forces, collapse of cabin structure, and crushing beneath engines and gear boxes. Head injuries are especially common among pilots, due to their exposed forward location. Protective helmets considerably reduce the likelihood of head injury. They are routinely used by military aviators, but seldom by civilians.

Fire is of special concern in helicopter crashes. The fuel cells cannot be located any great distance from the occupants, and are usually directly beneath or behind the cabin. Many victims survive the crash only to die in the subsequent fire. The U.S. Army developed a crashworthy fuel system to prevent these deaths.

Crashworthy helicopter design is typified by the U.S. Army UH-60 Blackhawk. Attenuation of crash forces is provided by the landing gear (designed to absorb approximately 15 G) and the vertically-stroking seats, which absorb approximately 30 G. Stroking of the seats also moves the pilots down and away from the windscreen. A crashworthy fuel system will prevent fuel spillage and fire up to approximately 80 G. The entire design is such that the usual 50 G limit of survivable crash forces has been pushed to approximately 80 G (in the vertical axis), and post-crash fire will not be a factor until crash forces have exceeded the limit of survivability.

Air Transport Aircraft

A wide range of aircraft types are used in transport operations. Small "airliners" are similar to the larger general aviation aircraft. At the other extreme are the wide-bodied airbuses used in intercontinental service. The "typical" modern airliner is powered by two, three, or four turbine engines. It carries from a few people (as on training flights) to several hundred. Take-off and landing speeds are on the order of 250 km/h. Commonly these aircraft cruise at 900 km/h, at altitudes up to 12 km.

Accidents with ground impact at high speed result in disintegration of the aircraft and its occupants. Intermingled aircraft and human remains may be scattered over thousands of square meters. Fortunately, such crashes are uncommon. Crashes during take-off or landing are much more common. Typical of such crashes, speeds are relatively low and impact angles shallow. Deceleration time is prolonged, and peak G-loading is reduced. Energy is dissipated as the aircraft slides along the ground and its structural components are deformed by crash forces. The fuselage may remain relatively intact.

About one-half of the fatalities which occur in air transport accidents are not the result of impact injuries. Rather, they result from thermal-toxic injuries during the post-crash fire. To escape from the wreckage, passengers and crew must successfully reach, open, and pass through doors, emergency exits, or rents in the fuselage. As many as three-quarters of the exits are not used because of jamming, blockage, fire, smoke, or other factors.

Injuries sustained during the decelerative phase of a crash, such as legs broken by flailing against seats, head injures from impact against seats and tray tables, or perineal and buttocks injures associated with downward failure of seats, may have incapacitated the victims. Correlation of injury patterns with crash dynamics and structures in the vicinity of each victim is essential to understanding the mechanisms of injury.

It should be noted that, while considerable attention has been given to improving crash survival and occupant escape in military fighter-type aircraft and helicopters, and recently to improving crash safety standards for automobiles and other ground vehicles, rather little work has been directed toward providing similar protection for air transport passengers and crews.

Fire may envelop a crashed airliner in a matter of a few seconds, or it may take several minutes. The cylindrical fuselage may act as a flue or chimney drawing fire through the passenger compartment with gale-force winds. In addition to large quantities of smoke and carbon monoxide, a wide variety of other combustion products are liberated from burning fuel, lubricants, hydraulic fluid, and the plastic materials used in aircraft interiors. Among these combustion products are HCN, NOx, HF, and HCl. The toxicology of these various combustion products, and their effects in combination with the inevitably present carbon monoxide, are the subject of ongoing research.

Fighter-Type Aircraft

These high performance airplanes carry either one or two aviators. Two-place aircraft may have side-by side or tandem seating and two sets of flight controls. Take-off and landing speeds of 250-275 km/h are common. Cruising speeds are generally in the range of 900-1000 km/h. Many of these aircraft types are capable of sustained supersonic flight. Operating altitudes in excess of 12 km. are not unusual. However, some fighter-type aircraft are also routinely flown at high speed and low altitude, as on gunnery ranges or terrain-following missions.

When a modern fighter aircraft crashes it usually disintegrates. High speeds and/or high angles of ground impact produce crash scenes aptly described as "smoking holes". If the victim remains in the aircraft at ground impact the body is likely to be fragmented. Specific kinds of missions of specific types of aircraft are also associated with an increased incidence of accidents, e.g. low-level bombing runs at night, ground-attack, etc. Fighter aircraft are frequently operated near the limits of human physiologic and psychomotor capability. Similarly, the aircraft are sometimes operated near the limits of their aerodynamic and structural capability. The Aircraft Accident Investigation Board has access to the accident history of the aircraft type involved in each crash. This well-documented "epidemiology" of military aircraft accidents is extremely useful to the crash investigators because it alerts them to common "failure modes" of both the machine and its human operators.

Fighter aircraft are equipped with ejection seats, designed to propel the seat and its occupant clear of the aircraft, release the restraining harnesses, separate the occupant from the seat, and initiate parachute opening. Typical vertical velocity during ejection is 15-20 m/s, with peak velocity being achieved in about 1.25 meters. The aviator is subjected to an 18-20 G. acceleration. Elapsed time from initiation of ejection to parachute opening is about one second. During bail-out at high altitude parachute opening is automatically delayed, and the aviator free-falls to lower altitude (about 4500 meters) before an aneroid device deploys the parachute.

Modern ejection systems have an excellent record of reliability when used within the so-called "ejection envelope"; that is, within the limits of altitude, airspeed, aircraft attitude, and sink-rate for which the system was designed. Most fatalities occur because the ejection system is activated so late in the accident sequence that effective parachute opening cannot be achieved prior to the victim striking the ground. Thus, if in-flight escape was attempted but unsuccessful the victim's body tends to be relatively intact. Injury patterns reflect lethal events which occurred during or subsequent to ejection. Occasionally ejection is successfully accomplished and parachute opening achieved, but the aviator is killed by landing in electric power lines, drowning, being dragged across the ground by high winds, or descending into the flaming wreckage of his own aircraft.

Aviators who operate high performance military aircraft wear life support equipment including protective helmets, oxygen masks, parachutes, and G-suits. Malfunction of any of this equipment may be a cause factor in an accident, or may preclude successful in-flight escape from an impending crash. Thus, it is essential that the Medical Investigator/Pathologist have the expert assistance of a military Flight Surgeon and/or Aviation Physiologist who is often able to recover and assess the functional state of key life support components.

A note of caution is warranted. Military aircraft sometimes crash with live ordnance, such as bombs and rockets aboard. Unfired ejection seats contain ballistic and rocket charges which may remain capable of causing serious injury or death should they be inadvertently activated. The military services provide ordnance specialists who will disarm these devices. Personnel not essential to rescue and fire-fighting operations should not approach aircraft wreckage until it has been declared "safe" by the Fire Marshall and/or the ordnance specialists.

GENERAL CONSIDERATIONS

As in the investigations of other modes of

violent death, autopsies of aviation accident victims are usually performed while only incomplete and sometimes inaccurate information is available from the death scene. Consequently, free exchange of information between pathologist and crash-site investigator is essential. Premature conclusions based solely on autopsy findings must be avoided.

The pathologist should familiarize himself with the general features of the aircraft involved, the nature of the accident, and the specific interpretative problems likely to be encountered. A tour of the crash site, in company with the Flight Safety Investigator or Flight Surgeon, is especially helpful. An appreciation of the physical setting and some concept of crash dynamics greatly assists in the interpretation of injury patterns. The investigating Flight Surgeon should attend the autopsy.

The pathologist is seldom able to make an initial examination of aircraft crash victims while they are still in the wreckage. Usually the bodies will have been removed by rescue or fire fighting personnel. Frequently the locations of victims within the aircraft will not have been recorded. Since interpretation of the postmortem examination depends on detailed knowledge of each victim's immediate surroundings and possible role in aircraft operation, this type of scene disturbance, innocently motivated, can jeopardize the entire Human Factors investigation. Therefore, the pathologist's first task is to establish the seating position location of each victim within the cabin/cockpit. Sometimes photographs will have been taken of the victims in the wreckage. Often it will be necessary to identify and interview the people who moved the bodies.

The pathologist is dependent on highly specialized technical assistance to interpret his observations. Injury patterns not understood at the time of autopsy may have critical significance when related to specific aircraft structures and crash dynamics. Similarly, the hardware/operations investigators and Flight Surgeon must base many of their conclusions on autopsy and toxicological findings. Documentation of observations made during autopsy is of extreme importance. The Pathologist's primary responsibility is to observe and to document. Final interpretation must be a collaborative effort between the pathologist and the other Human Factors investigators within the framework of the entire accident investigation.

COMMENTS ON DOCUMENTATION

Autopsy findings are eventually reduced to a written narrative, with accompanying anatomic drawings or diagrams, which constitutes the work product of the pathologist. These materials become part of the accident report prepared by the Flight Safety Investigator or the military Aircraft Accident investigation Board. Photographs and roentgenograms of crash victims are not ordinarily forwarded as part of the official record, but rather are retained in the files of the medical investigator/pathologist. Photography and roentgenography not only provides additional means of documentation, but, when properly used, are powerful investigation tools.

Photographs

Photographic documentation begins at the crash site. The primary investigators take numerous photographs of the aircraft wreckage and surrounding terrain. These photographs depict damage to aircraft structures but only incidentally show the injuries to aircraft occupants or body positions. The pathologist should, therefore, be prepared to take his own photographs of the crash scene. Emphasis should be placed on the cockpit/cabin area of the aircraft and the locations at which bodies were recovered. Ideally, this photographic record begins before the bodies of the victims are removed. Crash sites, especially those of general aviation accidents, are seldom secure. Wreckage is soon disturbed and the value of scene information rapidly degraded.

Photographs of crash victims, clothed and then unclothed, with special attention directed toward external manifestations of injuries, even those injuries which appear inconsequential, should be taken under the good lighting conditions of the morgue. Internal injuries and significant natural disease processes should be photographed. Thorough photographic documentation of broken hardware and human injuries greatly facilitates retrospective analysis of crash injury patterns.

Roentgenograms

Roentgenographic examination of crash victims can provide significant information which is difficult or impossible to obtain by other means. Roentgenograms can be used to establish positive identification of crash victims when fingerprint or dental comparison are not feasible. Anatomic sites, such as maxillary and frontal sinuses which are important in aviation physiology but seldom examined

at autopsy, are readily visualized. Radio-opaque foreign objects imbedded in bodies, such as bits of flight instruments or bomb fragments, are readily demonstrated. "Control injuries", those blunt force injuries of hands and feet that indicate the aviator was attempting to control the aircraft at impact, are more easily demonstrated roentgenographically than by autopsy, as are the vertebral compression fractures associated with high vertical loads.

TOXICOLOGY IN AVIATION ACCIDENTS

Toxicologic analysis of body fluids and tissues of persons fatally injured in aviation accidents is an essential part of the Human Factor investigation. Collection of appropriate specimens is part of the autopsy. Chemical agents of primary concern are ethanol, carbon monoxide, prescription and over-the - counter medications, and illicit drugs.

Ethanol

The intact body without decomposition presents no problems in ethanol level interpretation, assuming proper specimen collection and handling. Many aircraft accident victims are fragmented, with variable amounts of decomposition. In decomposing bodies, postmortem bacterial production of alcohols will artifactually raise the ethanol, although rarely above 0.05g/dL. Bacterial ethanol production is accompanied by other alcohols and congeners such as n-propanol and n-butanol; presence of these compounds indicates postmortem artifact, rather than ingestion. The ideal specimen is vitreous humor. It is protected from all but severe trauma, and decomposes slowly. Urine has similar qualities; blood is usually easily gotten, but decomposes quickly.

Carbon Monoxide

The toxicity of carbon monoxide increases as the partial pressure of oxygen decreases at higher altitudes. Thus, postmortem blood levels of carbon monoxide which might be of little significance at sea level produce significant pilot incapacitation at altitude. An elevated blood carbon monoxide level and soot in the airways may result from an in-flight fire or inhalation of combustion products in a post-crash fire. Carbon monoxide levels in occupants alive in fires occurring in small cabins (generally fewer than 10 passengers), or those exposed to a "fireball" of fuel will often be quite low. Rather than the 50 - 70% carboxyhemoglobin saturation typically seen in house fire victims, saturations are often 10 - 20%, scarcely above the baseline level for a heavy cigarette smoker. These deaths are probably due more to oxygen depletion and carbon dioxide production than to carbon monoxide. Thus, interpretation of postmortem carbon monoxide levels requires detailed knowledge of the crash sequence and the other autopsy findings.

Drugs

Toxicology examination of pilots (and other aircrew members) should include a "drug screen" and quantitation of any drug(s) detected. A pharmacological agent may be present in sufficient concentration to be incapacitating and, therefore, a "cause factor" in an accident. The presence of therapeutic levels of certain drugs may provide clues to symptomatic natural disease. For example, an antihistamine would suggest the possibility of an upper respiratory tract infection which might predispose to acute barotitis media or barosinusitis, the attendant pain of either being capable of causing distraction or partial incapacitation during a critical phase of flight.

Detection of quinidine would suggest a history of heart disease not documented in the victim's medical records. Similarly, finding one or more of the various tranquilizers would prompt further inquiry into the aviator's psychological and psychiatric history.

The victim's personal effects should be searched for medication containers, and in instances where prescription drugs are discovered the prescribing physician should be contacted in an effort to develop further medical history.

NATURAL DISEASE IN AVIATION ACCIDENTS

Occasionally aviators conceal manifestations of serous chronic illness, such as angina pectoris, diabetes mellitus, idiopathic epilepsy, or malignancy form their physician. Others choose to fly while suffering from acute conditions, such as respiratory tract infections, gastroenteritis, or migraine headache. Sudden collapse and/or death may result from acute coronary arterial insufficiency, ischemic or hemorrhagic cerebral infarcts, ruptured intracranial aneurysms, or spontaneous pneumothorax. Incapacities ranging from mild physiological

disturbance to sudden death have been clearly established as the cause of specific accidents.

At autopsy, pilots manifest the same range of natural diseases as their passengers or any other group of reasonably healthy adults who die violent deaths. The incidence of atherosclerotic cardiovascular disease in military aviation mishap autopsies is approximately 15%. The mere presence of pre- existing disease does not mean that it was a factor in causing the accident. To avoid serious error, autopsy findings must not be interpreted out of context. For example, severe coronary arterial atherosclerosis and a healing myocardial infarct in a pilot might mean that a crash occurred because of in-flight incapacitation and/or death of the aircraft operator. The interpretation is quite different, however, if the engineering analysis of the aircraft wreckage, corroborated by the flight data records, indicates that the aircraft, while in straight and level flight, sustained a major structural failure due to a design deficiency and metal fatigue. A brain tumor might have initiated a grand mal seizure causing complete incapacitation of the pilot, loss of control, and crash. The tumor might be an incidental finding if that pilot could not have been in control of the aircraft at any time in the crash sequence.

OBJECTIVES OF THE AUTOPSY

The objective of the autopsy examination of aircraft crash victims can be summarized as a series of questions:

1. Who died?
2. What was the "cause of death"?
3. What was the manner of death?
4. What specific interactions between victim and aircraft structures/components resulted in injures? 5. If the Aircraft had provisions for in-flight escape, why did the victim(s) fail to escape?
6. If the victim(s) survived the decelerative forces of the crash, why did they fail to escape from the lethal post-crash environment?
7. What role, if any, did the victim(s) play in causing the crash?
   A. Who was flying the aircraft?
   B. Was the pilot incapacitated?
   C. Were physiological aberrations initiating or contributory cause factors in the accident?

The injuries seen at autopsy are most conveniently and usefully separated by the location of injury (head/neck, abdomen, extremity, etc.) and the mechanism of each injury. Injury mechanism may be separated into the categories of **Decelerative, Impact, Intrusive,** and **Thermal.**

Traumatic Injuries

Head Injuries. In aircraft accidents, the head and neck region is especially susceptible to injury. Head injuries alone comprise the most frequent cause of death in aircraft accidents. Death often results from the head striking the instrument panel. Preventive measures, such as helmets and shoulder restraint systems, have reduced head injuries. However, the head can still strike the instrument panel, even with an effective torso restraint system in place, as a result of buckling of the fuselage. Also, since the crash impact can have enough energy to separate the helmet from the head, injury may follow. A fatal head injury can be sustained even if the helmet remains in place and intact. In this case, the helmet may have distributed impact forces widely over the head, leaving the scalp and skull undamaged while fatal forces were transmitted to the brain.

Severe impact forces can cause comminuted ("eggshell") fractures of the skull, or partial to complete decapitation. However, skull fractures can be subtle and require close examination at autopsy to be detected. The dura must always be removed and the skull base examined for hidden fractures. Force from an impact to the chin may be transmitted through the arch of the jaw to the temporomandibular joints, causing a basilar skull fracture through the middle cranial fossae. Forces transmitted up the spine in $+G_z$ impacts can cause ring fractures around the circumference of the foramen magnum. Linear fractures of the skull most often are found in the plane in which the force was applied.

Spinal Injuries. Compression vertebral fractures are most often caused by $+G_z$ vertical forces greater than 20 G (usually greater than 26 G), but may occur with forces as low as 10 to 12G. Shearing (or transacting) fractures of the vertebral column can result from horizontal forces of 200 to 300 G.

A combination of G_x, G_y, and G_z forces usually causes the vertebral fractures. The resultant fracture pattern has been described as a "crowbar fracture" with compression of the anterior portion of the vertebra and pulling apart of the posterior bony ligamentous portions in tension. At autopsy, gross lacerations of the brain stem and spinal cord or the vessels covering them and

parenchymal hemorrhages within the brain stem and spinal cord may be found.

Certain crash circumstances, coupled with the potential "hangman's noose" formed by a loop consisting of the inferior edge of the helmet, the nape strap, and the chin strap, may produce a fracture dislocation at the axis (C2 and C1) and a fracture of the posterior arch.

Internal Injuries. Because the internal organs are suspended only by attachments within the abdomen and the chest, and are asymmetric in size and weight, they may experience torsional and shearing forces that can produce internal tears. Penetrating injuries may be caused by external objects, parts of the cockpit controls, or broken ribs.

The heart or great blood vessels may be compressed between the sternum and vertebrae and, as a result, rupture. Their rupture may also occur following a compression force to the chest or abdomen that transmits hydrostatic pressure backwards toward the heart. Transverse laceration of the aorta at the root or ligamentum arteriosum is due to traction by the relatively unrestrained heart moving in the chest on any axis. Vertically oriented lacerations of the thoracic aorta are more likely due to lacerations by broken ribs.

Laceration, tears or rupture of the abdominal organs may be produced by blunt trauma to the abdomen. Blunt trauma to either the thorax or abdomen may result in a ruptured diaphragm.

Extremity Injuries. Injuries of the extremities may be caused by impact with surrounding structures or by free or uncontrolled movement (i.e., flailing) of the extremities during the crash sequence. The term "flailing" is usually associated with ejection injuries but can be used to describe injuries in the cockpit. Examples are incapacitating leg fractures caused by upward buckling of the aircraft fuselage, and "dashboard femoral fracture" caused by the knee impacting the instrument panel.

Injury patterns of the hands and feet may be used to identify who was in control of the aircraft, or even if a single pilot actually had the controls at the time of the crash. These injury patterns have been labeled "control injuries." Fractures of the hands may occur in those who are tightly holding the wheel or stick during the crash sequence. On impact the energy transmitted through the pedal controls may fracture the foot. The imprint of the pedal may rarely be transferred to the pilot's boot. In general, fractures of the carpal, metacarpal, tarsal, and metatarsal bones, in conjunction with laceration patterns on the palms and soles, serve as good evidence that the aviator was attempting to control the aircraft.

For further discussion the reader is referred to classic articles on control injuries by Coltart and Krefft. Coltart used the term "aviator's astralgus" to describe fractures of the talar neck in pilots of aircraft equipped with toebrakes. Krefft examined the mechanics of these control injuries. If the pilot has clasped the control stick at the very instant of impact, the area between the thumb and index finger will experience "exceptional strain" caused by the impact jolt. A distinctive stick grip pattern of injury may result that consists of abrasions, contusions, soft tissue tears, or fractures in this area. Similarly, serial transverse fractures of the metacarpals, especially if dorsally displaced, indicate the pilot was gripping the control stick. If the crash force is very violent, the proximal joint of the thumb may become completely crushed or even severed, and fractures of the distal ulna and radius may be seen. This type of hand injury is characteristic of jet aircraft crashes. It should be noted that these control injuries are located on the flexor sides of hands and soles, whereas flailing contact injuries are usually found on the extensor surfaces of the distal limbs. Krefft also discusses how these control injuries are reflected in typical damage to gloves and boots (e.g., tears, characteristic patterns, impression marks, or traces of color).

Ejection Injuries. The main injuries associated with ejections and windblast from high speed ejections are flailing injuries of the head, neck, and extremities that include dislocation, fractures, and maceration. The flailing motion is similar to "cracking a whip" with force being concentrated more distally. This motion produces fractures of the tibia, fibula, radius, and ulna more frequently than of the femur and humerus. The force generated at the anterior edge of the ejection seat may cause femoral fractures. There can also be superficial skin "stretch lacerations" similar to those seen on pedestrians struck by automobiles. During the ejection sequence, the opening shock of the parachute may cause injury if the ejection occurs at high altitude or high velocity or both.

Decelerative Injuries and the approximate G forces involved:

Vertebral body compression fractures: 20 to 30 G.
Tears of aortic intima: 50 G.
Transection of aorta: 80 to 100 G.

Fractured pelvis: 100 to 200 G.
Transection of vertebra: 200 to 300 G. (Through vertebral body, not intervertebral disc)
Total body fragmentation: 350 G or greater.

It is important to base the estimation of decelerative G-forces on decelerative injuries only; the unintentional inclusion of impact injuries in G-force estimation is a common problem.

Impact Injuries: Injuries due to human-machine interaction. These should be related to cockpit/cabin structures by careful examination of both the cockpit of the crashed aircraft and an identical intact aircraft. These injuries consist of blunt force trauma: patterned contusions, abrasions, lacerations, and fractures. There may be transfer of tissue or hair to cockpit surfaces. Flail injuries may result from violent extremity movement in high speed ejection (e.g., Q forces), or may be seen in non-ejection mishaps due to inertial forces. It must be remembered that deformation of the cockpit during the crash may result in a transient, but still fatal, loss of occupiable space. Differential injury (e.g.. primarily left versus right sided injury) assists in determining directionality of forces, as may examination and interpretation of roentgenograms. If the crash is due to mid-air collision with breakup and free-falling bodies, the injuries (if any) due to the collision and aircraft breakup should be differentiated from ground impact injuries.

Intrusive Injuries: Most commonly seen in helicopter crashes, either due to an unbalanced rotor going through the cockpit/cabin, or striking an unseen high-tension wire at speed. Less common are tree strikes. Bird strikes in the cockpit can cause extensive injury to the pilot, including decapitation. Occasionally mid-air collisions result in injury to occupants, as well as aircraft damage.

Thermal Injuries: The most critical issue is determining if the victim was alive in the fire. Artifacts of postmortem fire exposure are discussed below. Differentiating injury from mere artifact is sometimes quite difficult, but always very important, particularly when looking for control injuries.

ENVIRONMENTAL FACTORS

Hypoxia

One of the most important and least readily solved problems confronting aircraft accident investigators is the detection of acute antemortem hypoxia. Hypoxia may occur insidiously (e.g., prolonged flight at altitude) or suddenly (e.g., rapid decompression at high altitude). Lactic acid elevation in brain is theoretically a fairly sensitive and specific test for such hypoxia. Practically, however, this test is really of no use, since such testing requires the intact brain; loss of control due to hypoxia results in a high speed uncontrolled descent with extensive fragmentation on impact. In over 15 years OAFME has not had a single fatal mishap in which hypoxia might have been involved in which there was adequate sample to test.

Fire

In-flight fires can cause streaming patterns of soot deposition on the victim's body and aircraft surfaces. The ignited fuel at impact causes a fireball that can cause first- and second-degree burns of unprotected skin surfaces. It should be recognized that "burning to death" does not occur in crashes: the victims die of impact injuries and/or inhalation of carbon monoxide and other products of combustion well before sustaining burns. Post-crash fire injury patterns can be very difficult to interpret. Distal extremities are often fractured in charred bodies. Differentiation between control injuries and postmortem thermal fractures is often very difficult. It is better to err on the side of thermal fracture than to diagnose a control injury that does not exist.

Soot found in the mouth, nose, or elsewhere in the naso- or oro-pharynx may indicate that the person was alive at the time of the fire. However, this finding is not conclusive. The soot may have been the result of agonal respiratory excursion. Soot in the distal trachea (below the vocal cords) and bronchi is good evidence of inhalation of combustion products. The pathologist may have to examine multiple sections of the trachea and distal airways microscopically looking for soot. This, combined with elevated carbon monoxide levels, would confirm that the victim was alive at the time of the fire. If the victim is exposed to the fireball and inhales the atomized burning fuel, thermal burns of the trachea or even bronchi may be seen. Conversely, exposure to the fireball may result in laryngospasm with no thermal burns below the level of the vocal cords and very low levels of carboxyhemoglobin. Burns seen in the airways of those not exposed to a fireball are generally chemical, rather than thermal, in nature. They are due to the noxious products of

combustion from many synthetic and some natural materials.

A carboxyhemoglobin blood level greater than 10 percent usually suggests significant carbon monoxide exposure before death. Levels up to 10 percent can be encountered in smokers (usually 3-6 percent) and levels up to 7 percent may be found in nonsmokers from industrial and metropolitan areas.

In fire fatalities the carboxyhemoglobin level is usually a function of the size of the enclosed space and of the exposure time. In transport aircraft crashes, victims of the fire may have carboxyhemoglobin levels ranging from 30-60 percent. Levels of 10-30 percent are usually seen in fire victims in smaller aircraft crashes. A level of 30 percent generally relates to a survival of 1 to 17 minutes.

Artifacts of postmortem exposure to fire are often misinterpreted by the inexperienced pathologist or investigator. Heat contraction of muscles produces a "pugilistic" appearance with flexed hips, arms, and legs, as if the victims were protecting themselves from the fire. The stronger flexor muscle groups are simply dominating the extensor muscles. Skin splits due to contraction may be confused with lacerations. Burning away of the abdominal wall with extrusion of intestine is often similarly misinterpreted. Skull fractures due to heat (rather than impact) often are "delaminating": the outer table of the cranial bone will flake off, exposing the medullary bone. Further heat exposure results in the inner table and medullary bone flaking off together. The delamination is due to differential expansion of the curved skull as it is heated from without. Epidural hematomas, usually associated with head trauma and skull fracture, are merely an artifact in burned bodies, unless directly related to a linear fracture.
After exposure to heat, hair color observation may be unreliable. Visual impressions of the age of a body cannot be relied upon. Height and weight are similarly unreliable.

Water (Drowning)

In fatal aircraft accidents occurring in water, it is natural to ask whether death was caused by traumatic injuries or drowning. When injuries are severe, the death is traumatic. Drowning should be considered as the cause of death if injuries are minor or not likely to cause death. Some pathological findings (anatomic and chemical) are compatible with drowning. However, no simple finding (autopsy or laboratory) is diagnostic of drowning. A diagnosis of drowning can be made only after excluding all other diagnoses.

In a body recovered from water and thought to have drowned, the only external finding may be a mushroom of froth in the nose and mouth (the "foam cone"). This froth is considered nonspecific but may be highly significant if circumstances suggest drowning. Occasionally petechial hemorrhages may be found in the conjunctivae, most often in the lower eyelids. Rigor mortis may set in early, due to exertion. Some external findings occur after death and should not be confused with premortem trauma. Abrasions may be found on the skin surfaces exposed to the bottom of the body of the water as the drowned body drifts along the bottom. The skin of the hands and feet may appear wrinkled after prolonged exposure to the water. Finally, there may be postmortem mutilation of the body from sharks, crabs, lobsters, fish, turtles, etc. This is initially concentrated around the soft parts of the face (lips, eyes, nose), or around injuries.

Internal findings in most drowning cases include heavy congested lungs secondary to aspirated water and edema fluid. Petechial hemorrhages under the pleura may be seen as well as hemorrhages into the temporal bones.

Unless a drowned body is kept afloat by a flotation jacket or air caught under the clothing, it will sink. Gas is produced by decomposition and the body ultimately rises to the surface. The ability of bacteria to proliferate will determine the time required for the body to float to the surface. Bacteria grow faster in warm water, in fresh water, and in stagnant water and will grow slower in cold water, in sea water, and in rapidly moving water. Obese bodies should rise sooner than lean bodies.

Many controversial chemical tests have been proposed to help with the diagnosis of drowning. They are based on the idea that water was aspirated with alteration of blood volume and electrolytes. Similarly, the presence of diatoms in the lungs has been proposed as a "drowning test". While frequently used in Europe, these tests are rarely used in the U.S. because a thorough investigation of circumstances and examination of the scene has been found to be more reliable than any laboratory test.

Aviation Pathology Notes

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I. Office of the Armed Forces Medical Examiner

A. **Notification required for deaths of all active duty military** personnel, including aircraft accident victims.

1. 24-hour telephone number
    a) Commercial **(301)319-0000**
    b) (800)944-7912
2. Information required
    a) Number of fatalities with names and SSN if available
    b) Local Jurisdiction Coordination
    c) Location of Remains
    d) Location of Mishap
    e) Aircraft type and brief description of mishap
    f) Contact names and number(s)

B. Consultation by Armed Forces Medical Examiner System

1. Aviation and Forensic Pathology Consultant to Mishap Investigation Board -- Consultant to NTSB.
2. On-site investigation team if Exclusive Federal Jurisdiction or if local medico-legal authority (coroner or Medical Examiner) will release jurisdiction to the military, is willing to share jurisdiction, or will allow military pathologists to perform autopsies under his or her jurisdiction.
3. Aviation Pathology Consultation
    a) Evaluate mishap site and wreckage
        1) AFME on-site team leader will usually request helicopter support for aerial photography
        2) Local Army National Guard or Reserve aviation units are usually very supportive when requested if USAF rotary wing assets are not available
        3) Simple, helicopter-based 35mm photography is very helpful for reconstructing the mishap, mishap analysis and review by the OAFME, and board briefings

Paper presented at the AGARD AMP Lecture Series on "Injury Prevention in Aircraft Crashes: Investigative Techniques and Applications", held in Farnborough, UK, 24-25 November 1997, and Madrid, Spain, 1-2 December 1997, and published in LS-208.

b) Post-mortem examination of fatalities
c) Assist investigators with injury pattern analysis and mishap sequence reconstruction.
d) Written preliminary anatomic diagnosis list for all fatalities is provided for the investigators before the AFME consultant team leaves the area.
e) Provide appropriate documentation to board.
    1) Autopsy report within 5 working days of return to office, usually sent to NTSB / pathologist by express mail or FAX
    2) Photographic proof sheets by express mail within 5 working days of return to office and additional photographic products as requested by investigators.
    3) Toxicology report(s) within 10 working days of receipt by the OAFME Division of Toxicology in Washington DC. Report(s) sent by FAX or Express Mail

II. The Aircraft Mishap Investigation

A. Purpose of Accident Investigation
  1. Prevent Accidents
    a) Identify cause factors
    b) Improve procedures and/or equipment
  2. Minimize Injuries
    a) Identify injury mechanisms
    b) Improve procedures and/or equipment

B. Investigation Operations
  1. Aircraft mishap investigation is a multi-disciplinary venture, usually involving local, state, and federal agencies in the initial stages.
    a) Local law enforcement personnel and emergency medical response teams are generally the first to arrive on an accident site. As in any emergency, their first priority is to provide assistance to the survivors.
    b) After this is accomplished, the crash site is secured to prevent looting and preserve evidence at the scene. There is a tendency by some rescue personnel to remove bodies and wreckage before proper documentation and legal authorization. This should be discouraged as valuable information used in accident reconstruction and injury pattern analysis is lost. Removal of remains from the mishap site without proper legal authorization could make

investigators subject to criminal prosecution.

2. Documentation of the crash site
    a) The location of bodies and body parts in relationship to the wreckage is documented using a grid system or by measuring from fixed references points. Flags or stakes with sequential numbers are placed at the site of each body or body part.
    b) The remains are then photographed before placement in a body bag for transport to the morgue. Under no circumstances should personal effects (i.e. jewelry, wallets, etc.) be removed from the body at the site. Clothing should remain on the body.
    c) Personal effects that are not on the body are numbered separately and their location in relationship to the body is noted. This may help establish tentative identification of a victim.
3. Photography
    a) The entire accident site is photographed since film is a cheap and excellent means of permanent documentation. The wreckage is photographed at different angles and the fatalities are photographed before removal to the morgue. The cockpit of the aircraft is photographed to help correlate injury patterns found on the bodies of the pilots.
    b) Ideally, aerial photographs of the crash site are obtained. This enables the investigator to easily evaluate and conceptualize the entire wreckage dispersion pattern including ground gouges produced by pieces of the aircraft. Infrared aerial photography can sometimes be used to show fuel spillage patterns and to enhance ground gouges.
4. Preventive Medicine
    a) Site safety
    b) Bloodborne Pathogens

C. TAKE THE PATHOLOGIST TO THE MISHAP SITE !

III. Survivability Analysis

A. Crash Forces
1. Definition
    a. Crash - a sudden change in velocity (deceleration) resulting in damage to aircraft and contents.
    b. Acceleration - rate of change of velocity = change in velocity

divided by the time required for the velocity change.

c. Force - mass time acceleration (or deceleration)

2. Data for mathematical estimation is derived from crash site evaluation, wreckage analysis, instrument analysis, radio transmissions, radar plots, witness statements, mission plans, operational instructions, etc.
   a. estimate aircraft velocity
   b. estimate ground impact angle
   c. divide aircraft velocity into vertical and horizontal components
   d. estimate horizontal and vertical stopping distances
   e. estimate horizontal and vertical crush distances
   f. use standard physics formulas to estimate forces note: you must choose (or guess) an approximate decelerative pulse shape.

3. Example: An aircraft impacts a wall at 60 knots. The nose is crushed 5 ft and the wall is crushed 5 ft.

   Stopping distance s = 5 ft + 5 ft =10 ft

   Velocity change = 100 ft/sec (60 knots initial velocity)
   - 0 (final velocity)

   v = 100 ft/sec

   Equation: $G = v^2/64s$

   G = (100 ft/sec)(100 ft/sec)/(64 ft/sec-sec)(10 ft)

   G = 15G

4. **Additional methods of crash force estimation**
   a. Aircraft damage reflects decelerative forces applied to aircraft during the crash
   b. Injuries reflect decelerative forces experienced by occupants during the crash

5. **Human Tolerance to Decelerative Forces** - depends on both magnitude and duration force. Experimental human tolerance estimates for 0.1 sec decelerations are listed below.

+ Gz (Eyeballs Down)	25G
- Gz (Eyeballs Up)	15G
$\pm$ Gx (Eyeballs In or Out)	45G
$\pm$ Gy Eyeballs Side	20G

B. Occupiable Space
1. Aircraft crush and fragmentation
2. Temporary deformation of structures
3. Aircraft structure usually destroyed 30-50G
4. Restraint systems reduce required occupiable space
5. Blunt force injuries reflect competition for occupiable space with equal and opposite forces exchanged by the occupant and aircraft structures. These local force exchanges often greatly exceed the estimated crash forces for the center of mass of the aircraft-occupant system.

C. Post-crash environment
1. Fire
2. Water

D. Medical survivability analysis provides input to crashworthy design.

1. **Engineers use the "CREEP" concept** to assess and improve crash survivability through crashworthy design. The acronym 'CREEP" is used to organize the important aspects of crashworthy design. Note the similarities to the medical evaluation of survivability based on crash forces, occupiable space and post-crash environment. *(See Appendix for additional information on the CREEP concept and crashworthy design)*

C= container. Did the airframe maintain integrity and preserve and adequate volume of living space and prevent penetration by objects?

R= restraints. Were they worn correctly and did they function as designed? Did they prevent or contribute to injury?

E= environment. Were there any features of he mishap environment which affected the ability of the occupants to withstand crash forces or make a rapid egress?

E= energy absorption. Did the airframe and seat absorb enough of the crash-force energy to protect the occupants from exposure to intolerable crash forces?

P= post-crash factors. Did a post-crash fire, toxic fumes, poor communication, inadequate training, etc., affect survivability?

2. Major contributions of crashworthy design
    a) Crashworthy fuel system
    b) Energy absorbing seats
    c) Restraint systems

IV. Injury Analysis

A. External examination and documentation of injuries (photographs) are usually the most important parts of the post-mortem examination of aircraft mishap fatalities.
    1. These injuries are often not the fatal injuries
    2. They directly reflect interaction with environment
    3. They may suggest internal injuries which are fatal as well as define the injury mechanism.

B. Decelerative Injuries
    1. Note that human bodies are more resistant to disruption than aircraft. Thus the accident victims may be the best source for evidence with which to reconstruct the mishap sequence.
    2. Pure decelerative injuries provide a medical scale for estimation of crash forces. The most reliable points on this rough scale are high-lighted in the list below.
        a) Vertebral body compression -- 20 - 30 Gz
        b) Fracture dislocation C1-C2 -- 20 - 40 G
        c) Aorta intimal tear -- 50 G
        d) Aorta transection -- 80 - 100 G
        e) Pelvic fractures -- 100 - 200 G
        f) Vertebral body transection -- 200 - 300 G
        g) Body fragmentation -- > 350G

C. Impact injuries
    1. Blunt force injuries reflecting man-machine interaction in competition for occupiable space.
    2. Often dependent to some extent on restraint systems
    3. Examples
        a) Control panel head impact and skull fractures
        b) Compression injuries of fluid filled viscera and organs with a capsule
            1) liver
            2) kidney
            3) spleen
            4) bladder
            5) heart

c) Rib fractures and resulting lacerations

D. Ejection injuries
1. Flail
2. Environmental hazards
3. Aircraft impact and trace evidence transfer
4. Blunt force injuries from out-of-envelope ejections into trees or ground

E. Intrusive injuries
1. Wire strike
2. Rotor blades and other aircraft parts
3. Bird strikes (trace evidence)

F. Thermal Injuries
1. Flash burns and reconstruction
2. Artifacts
a) Pugilistic posture
b) Amputations and incineration
c) Skull incineration and epidural hemorrhage
3. Evidence of life in fire
a) Soot in airways
b) Carbon monoxide

V. Control Injuries

A. Evidence of intimate contact of hands and/or feet with aircraft controls at the time of impact

B. Radiographs of hands and feet are essential

C. Classical injuries
1. Hands
a) palmar lacerations and trace transfer to gloves
b) fracture-dislocation of base of thumb, often with evidence of forces transmitted through the wrist and forearm.
c) linear fractures of metacarpals
2. Feet
a) plantar lacerations and damage to flight boots (x-ray flight boots which may have bent metal plate)
b) fractures of metatarsals, calcaneus, or (especially) the talus

D. Dorsal injuries suggest flail while palmar and plantar injuries are more consistent with control injuries

E. The absence of control injuries means nothing

VI. Toxicology

A. Carbon monoxide
   1. excellent indicator of exposure to products of combustion while alive, in-flight or post-crash, differential usually based on other injuries and circumstances
   2. Stable postmortem -- not produced or eliminated

B. Cyanide
   1. useless because on instability, postmortem production, and absence of analytical standards
   2. worse than useless because commonly known by public and press to be a poison

C. Alcohol
   1. Postmortem production as part of decomposition process
   2. Depends on location and time of sampling
   3. Vitreous fluid is best sample, urine if vitreous is not available
   4. Blood is worst postmortem specimen since it is not protected from the bacteria which produce alcohol
   5. Postmortem alcohol production often sloppy with bacteria also producing chemicals such as acetaldehyde, acetone, n-propanol, and/or n-butanol

D. Drug screens
   1. Self medication
   2. Illicit drugs

VII. Identification

A. Presumptive
   1. Visual
   2. Personal effects
   3. Physical features
   4. Flight manifest

B. Positive
1. Dental comparison
2. Fingerprint and/or footprint comparison
3. DNA comparison
4. X-ray comparison

C. Identification is based on comparison of premortem records with postmortem observations. Without available premortem records, positive identification may be impossible regardless of how much postmortem data is available.

APPENDIX
Crashworthy Engineering Design
CREEP (Acronym)

Crashworthiness refers to the ability of basic aircraft structure to provide protection to the occupants during survivable impact conditions. Engineers evaluate aircraft crashworthiness by considering: Container, Restraint, Environment, Energy absorption, and Post crash hazards.

CONTAINER

Light airplanes and small transports (2-12 passengers) - During typical crashes the longitudinal structure collapses causing the floor to break up and seats to tear loose. Landing gear and engine may penetrate the cabin.

Medium Transport -- The fuselage fractures with complete separation of fuselage of under seats. There are often inadequate exists to permit escape and fuel is often under the passengers

Large Transports -- Fuel, located in wings and under the passengers is poorly contained if approach speed is above 150 knots. The fuselage often fractures in front of and behind the wings and the seats are torn loose from the floor. Exits may be blocked by fuselage deformation or fire, especially the exits over the wings which contain fuel.

Helicopters -- Transmission, mast, and rotor blades often penetrate cabin. Deformable structure is often limited and fuel tanks are adjacent to areas occupied by passengers. Occupants are particularly susceptible to crushing in roll-overs and inverted crashes.

High Wing Transports -- Structure is weaker because there are no longitudinal keel beams, only cross beams. The wings may crush occupants as they collapse and there is less crushable aircraft structure under the passengers.

RESTRAINT

The purpose of the restraint system is to delethalize the environment. Proper restraint systems minimize occupiable space requirements and prevent the occupants from becoming missiles which hitting aircraft structures. The occupants should decelerate with the aircraft.

Restraint System Characteristics -- Restraint systems should not be elastic

and should be as wide and thick as possible to distribute forces over the maximum area. Lap belts should cross the broadest part of the pelvis at a 45 degree angle. There should a be a simple, one-point release which is easy to operate without special training, but will not open accidently during a crash sequence or by the passenger's inadvertent actions. The restraint system should be attached (tie-down) to the most stable part of the aircraft.

Types of Restraint Systems

Lap Belt only - provides minimal restraint and subject may jack knife, resulting in injury to abdominal organs

Lap Belt and Shoulder Harness - provides good restraint for everything but lateral forces and submarining.

Four Point Harness - provides excellent restraint but occupant may slip down (submarine) through the bottom of the restraint system. This allows the lap belt to compress and injure abdominal organs.

Five point harness - includes a crotch strap which prevents submarining. This is the best restraint system but it is expensive and uncomfortable to wear.

ENVIRONMENT

Good aircraft design provides as much crushable structure as possible between occupants and the outer skin and enough stiffness so occupants aren't crushed. There should be sufficient safe exits and the structure should minimize roll-over and plowing during a crash. The interior should minimize loose objects during a crash. In the cockpit, collapsible, breakable control sticks, cyclics, collectives and control yokes to prevent injury to head or chest.

Seat design should recognize the vulnerability of the head and chest to injury as well as the effect of lower extremity injury in preventing escape (ankles broken by seats or feet trapped under rudder pedals).
Rear-Facing seats can provide the most crash protection for passengers if they are designed properly because they are better supported by the floor and will tolerate higher G loads but properly designed seats are much heavier than forward facing seats. Passengers are less comfortable and are more susceptible to flying debris during the crash.
Forward Facing Seats are the best compromise for economy, safety and passenger acceptance.

Side Facing Seats are very poor in a crash because proper restraint is extremely difficult.

ENERGY ABSORPTION

Crushable structure under the floor between the occupants and the bottom of the aircraft can attenuate vertical G's. The nose of aircraft (if crushable) can attenuate horizontal G's, but forces can actually be increased if the nose plows into the ground. For best crashworthy design, the nose should be sled-shaped and crushable. Seats should be designed to attenuate vertical G forces. Stroking tubes are the best seat energy absorbing devices but honeycomb and crushable foam are other acceptable materials. Foam rubber is not acceptable for crashworthy design because it is an elastic material which can store energy and then deliver it to the seat occupant all at once, producing dynamic overshoot which may double the crash forces experienced by the occupant.

POST CRASH HAZARDS

Fire is the most important post crash hazard. Post crash fire occurs in approximately 20% of crashes but 65% of all aircraft accident fatalities are due to post crash fire. If there is no post crash fire there is a 90-95% chance of survival but there is only a 60-65% chance of survival if there is a fire.

Post crash fires produce abundant heat which can severely injure the occupants, but most victims of post crash fire die from inhalation of toxic products of combustion such as carbon monoxide and other chemicals from upholstery and interior surface covering material. In addition, the fire uses all of the available oxygen in the closed cabin, producing a severely hypoxic environment very rapidly. Most victims of post crash fires are unconscious or dead by the time their bodies burn from the heat.

There are multiple ignition sources in an aircraft crash. Fuel, oil and hydraulic fluids burn readily once there is an ignition source. Fuels must be a vapor (or mist) to burn but once vaporized, all fuels are equally flammable. Advanced fuels such as JP-8 and anti-misting fuels are more resistant to ignition after a crash. Oil and hydraulic fluid have broad flammability ranges and cling to surfaces.

BIBLIOGRAPHY FOR LS-208

This bibliography was prepared by INTA (Instituto Nacional de Técnica Aeroespacial) at the request of, and with the help of, the Lecture Series Director, Major Francisco Rios Tejada, Spanish Air Force, MC.

Quest Accession Number : 94052220
A94-23055 AEROPLUS Issue: 9405
Modeling human body dynamic response to abrupt acceleration
Author(s): Obergefell, Louise (USAF, Armstrong Lab., Wright-Patterson AFB, OH); Kaleps, Ints (USAF, Armstrong Lab., Wright-Patterson AFB, OH)
Source Info: IN:SAFE Association, Annual Symposium, 31st, Las Vegas, NV, Nov. 8-10, 1993, Proceedings (A94-23015 05-54), Yoncalla, OR, SAFE Association, 1994, p. 341-346
Journal Announcement: IAA9405
Publisher: SAFE Association, Yoncalla, OR
Country of Publication: United States
Publication Year/Date: 1994; 940000
Document Type: CONFERENCE VOLUME - ANALYTIC
Language: English

The predictive simulation of human body dynamic response to abrupt accelerations encountered during emergencies can provide guidance for improved safety and crashworthiness design. The Articulated Total Body (ATB) model, a computer simulation program, is used for the prediction of human body dynamics during aircraft crashes, ejections, emergency escape, and other hazardous environment exposures. It is used to evaluate safety of proposed structures in the aircraft cockpit before prototypes are built or costly tests conducted. Because of its capability to predict both internal forces and external forces acting on the body, the ATB model can also be used in accident investigation. For example, the safety of a cargo plane was evaluated for head strikes with a head up display during a survivable crash, emergency escape through a chute was simulated to investigate body clearances and possible impacts with aircraft structures, body motion and limb flail during ejection were studied, and energy absorbing seats in a helicopter were simulated.

Classification: 54 (MAN-SYSTEM TECHNOLOGY/LIFE SUPPORT)
Controlled Term(s): HUMAN BODY / DYNAMIC RESPONSE / ACCELERATION STRESSES (PHYSIOLOGY) / AIRCRAFT SAFETY / FLIGHT CREWS / CRASHES / COCKPITS / EJECTION SEATS / HELICOPTERS / COMPUTERIZED SIMULATION

Quest Accession Number : 89A49205
89A49205 NASA IAA Journal Article Issue: 21
A study of nonstationary loads during the accelerated and abrupt motion of bodies of various shapes
Issledovanie nestatsionarnykh nagruzok pri uskorennom i vnezapnom dvizhenii tel razlichnoi formy
(AA)PODLUBNYI, V. V.; (AB)FONAREV, A. S.
PMTF - Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki (ISSN 0044-4626), May-June 1989, p. 83-88. In Russian., Publ. Date: 890600 Pages: 6 Language: RU (Russian)

The paper is concerned with the accelerated motion of several different bodies (a sphere, a cylinder, and a cone) from the position of rest to specified subsonic or supersonic velocities with various accelerations, including abrupt motion of a body with a specified velocity. The nonstationary aerodynamic characteristics of the bodies are obtained for different accelerations using a numerical method. An analytical procedure is proposed for calculating

the initial pressure distribution and maximum forces in abrupt motion.
V.L.
Category code: 02 (aerodynamics)
Controlled terms: *AERODYNAMIC CHARACTERISTICS /*CLASSICAL MECHANICS /*COMPUTATIONAL FLUID DYNAMICS /*LOADS (FORCES) / ACCELERATION (PHYSICS) / CONICAL BODIES / CRITICAL LOADING / EULER EQUATIONS OF MOTION / SUPERSONIC SPEED /

Quest Accession Number : 80A31592
80A31592# NASA IAA Journal Article Issue: 12
Injury dynamics in aircraft accident
(AA)SINGH, R.
Author Affiliation: (AA)(Indian Air Force, Institute of Aviation Medicine, Bangalore, India)
Aviation Medicine, vol. 23, Dec. 1979, p. 119-124., Publ. Date: 791200 Pages: 6 refs 8 Language: EN (English)
The impact forces encountered in aircraft accidents are generally abrupt accelerations of short duration, usually less than 1 sec., thereby causing mechanical damage that results in injuries to aircraft occupants. The discussion covers human tolerance to abrupt accelerations, along with aircraft crash injuries and dynamics. The basic causes and mechanism of the injuries are discussed. For quick retrieval of information to correlate injuries with aircraft environment during crash, a supplementary form is suggested to be incorporated into the current Form MS 1956.
S.D.
Category code: 54 (man-system technology/life support)
Controlled terms: *AIRCRAFT ACCIDENT INVESTIGATION /*CRASH INJURIES / HARNESSES / HUMAN FACTORS ENGINEERING / HUMAN TOLERANCES / IMPACT ACCELERATION / MAN MACHINE SYSTEMS / MECHANICAL SHOCK / PHYSIOLOGICAL ACCELERATION / SEAT BELTS /

Quest Accession Number : 70N40569
70N40569# NASA STAR Technical Report Issue: 23
Human tolerance to abrupt accelerations. A summary of the literature (Literature survey on human tolerance of abrupt accelerations)
(AA)MC KENNEY, W. R.
Corp. Source: Dynamic Science, Phoenix, Ariz. (D8686424) AVSER FACILITY.
AD-708916; AVSER-70-13 Publ. Date: 700500 Pages: 68 refs 0 Language: EN (English) Avail.: NTIS
Category code: 04 (biosciences)
Controlled terms: *ACCELERATION TOLERANCE /*HUMAN TOLERANCES /*IMPACT TOLERANCES / BIBLIOGRAPHIES / IMPACT ACCELERATION /

Quest Accession Number : 90N22547
90N22547# NASA STAR Technical Report Issue: 16
Aircraft crash survival design guide. Volume 3: Aircraft structural crash resistance / Final Report, Sep. 1986 - Aug. 1989
(AA)ZIMMERMAN, RICHARD E.; (AB)WARRICK, JAMES C.; (AC)LANE, ALAN D.; (AD)MERRITT, NORMAN A.; (AE)BOLUKBASI, AKIF O.
Corp. Source: Simula, Inc., Phoenix, AZ. (SL704492)
AD-A218436; USAAVSCOM-TR-89-D-22C-VOL-3 Contract: DAAJ02-86-C-0028 Publ. Date: 891200 Pages: 265 (Revised)
Language: EN (English) Avail: NTIS HC A12/MF A02

This five volume publication was compiled to assist design engineers in understanding the design considerations associated with the development of crash resistant U.S. Army aircraft. A collection of available information and data pertinent to aircraft crash resistance is presented, along with suggested design conditions and criteria. The five volumes of the Aircraft Crash Survival Design Guide cover the following topics: Design Criteria and Checklists; Aircraft Design Crash Impact Conditions and Human Tolerance; Aircraft Structural Crash Resistance; Aircraft Seats, Restraints, Litters and Cockpit/Cabin Delethalization; and Aircraft Postcrash Survival. This volume (Volume 3) contains information on the design of aircraft structures and structural elements for improved crash survivability. Current requirements for structural design of U.S. Army aircraft pertaining to crash resistance are discussed. Principles for crash-resistant design are presented in detail for the landing gear and fuselage subject to a range of crash conditions, including impacts that are primarily longitudinal, vertical or lateral in nature and those that involve more complicated dynamic conditions, such as rollover. Analytical methods for evaluating structural crash resistance are described.
GRA

Category code: 03 (air transportation/safety)
Controlled terms: *AIRFRAMES /*CRASHWORTHINESS /*DYNAMIC STRUCTURAL ANALYSIS /*FUSELAGES /*STRUCTURAL ENGINEERING / AIRCRAFT ACCIDENTS / CHECKOUT / LANDING GEAR / SEATS / SURVIVAL / TOLERANCES (PHYSIOLOGY) / VULNERABILITY /

Quest Accession Number : 80N33385
80N33385# NASA STAR Technical Report Issue: 24
Aircraft crash survival design guide. Volume 3: Aircraft structural crashworthiness / Final Report, Sep. 1977 - Mar. 1980
(AA)LAANANEN, D. H.; (AB)SINGLEY, G. T., III; (AC)TANNER, A. E.; (AD)TURNBOW, J. W.
Corp. Source: Simula, Inc., Tempe, Ariz. (SL704970)
AD-A089104; TR-7821; USARTL-TR-79-22C-VOL-3 Contract: DAAJ02-77-C-0021; DA PROJ. 1L1-62209-AH-76 Publ. Date: 800800 Pages: 274 refs 0 Language: EN (English)
Avail.: NTIS HC A12/MF A01

This five volume document has been assembled to assist design engineers in understanding the problems associated with the development of crashworthy U.S. Army aircraft. It includes not only a collection of available information and data pertinent to aircraft crashworthiness but suggested

DYNAMICS / ELASTICITY / ENGINEERING / FACTOR / FREQUENCY / HUMAN / INTEGRATION / MASS / MODEL / PERFORMANCE / PHENOMENON / PHYSIOLOGY / PICKUP / PROBLEM / RESONANCE / RESPONSE / SPINE / SUMMARY / SUPERSONIC / SYSTEM / TOLERANCE / WEIGHT /

Quest Accession Number : 90N22548
90N22548# NASA STAR Technical Report Issue: 16
Aircraft crash survival design guide. Volume 4: Aircraft seats, restraints, litters, and cockpit/cabin delethalization / Final Report, Sep. 1986 - Aug. 1989
(AA)DESJARDINS, S. P.; (AB)ZIMMERMAN, RICHARD E.; (AC)BOLUKBASI, AKIF O.; (AD)MERRITT, NORMAN A.
Corp. Source: Simula, Inc., Phoenix, AZ. (SL704492)
AD-A218437; USAAVSCOM-TR-89-D-22D-VOL-4 Contract: DAAJ02-86-C-0028 Publ. Date: 891200 Pages: 271 (Revised)
Language: EN (English) Avail: NTIS HC A12/MF A02

This five-volume publication was compiled to assist design engineers in understanding the design considerations associated with the development of crash-resistant U.S. Army aircraft. A collection of available information and data pertinent to aircraft crash resistance is presented, along with suggested design conditions and criteria. The five volumes of the Aircraft Crash Survival Design Guide cover the following topics: Design Criteria and Checklists; Aircraft Design Crash Impact Conditions and Human Tolerance; Aircraft Structural Crash Resistance; Aircraft Seats, Restraints, Litters and Cockpit/Cabin Delethalization; and Aircraft Postcrash Survival. This Volume (4) contains information on aircraft seats, litters, personnel restraint systems, and hazards on the occupant's immediate environment. Requirements for design of seats, litters, and restraints systems are discussed, as well as design principles for meeting these requirements and testing for verification that the systems perform as desired. Energy-absorbing devices for use in seats are described, as are various types of cushions. Delethalization of cockpit and cabin interiors is discussed, including the use of protective padding and the design of controls for prevention of injury. Finally, computerized methods of analysis for evaluation of seats, restraints, and the occupant's immediate environment are presented.
GRA

Category code: 03 (air transportation/safety)
Controlled terms: *AIRCRAFT ACCIDENTS /*CRASHWORTHINESS /* ENERGY ABSORPTION /*STRAPS /*SURVIVAL / AIRCRAFT COMPARTMENTS / AIRFRAMES / CHECKOUT / COCKPITS / COMPUTER TECHNIQUES / CUSHIONS / INJURIES / SEATS / STRUCTURAL ANALYSIS / TOLERANCES (PHYSIOLOGY) / VULNERABILITY /

Quest Accession Number : 66A29447
66A29447# NASA IAA Issue: 15
Problem of the resistance of man to the effect of intensive short-term angular accelerations (Abrupt angular acceleration effect on man, noting physiological responses such as blood pressure, EKG, EEG, cardiovascular, respiratory and nervous reactions, etc)
K voprosu ob ustoichivosti cheloveka k vozdeistviiu kratkovremennykh uglovykh uskorenii bol'shikh velichin
(AA)ORLOV, S. F.; (AB)TARDOV, V. M.; (AC)USTIUSHIN, B. V.
IN- PROBLEMS OF SPACE BIOLOGY. VOLUME 4 <PROBLEMY KOSMICHESKOI BIOLOGII. VOLUME 4<. EDITED BY N. M. SISAKIAN. MOSCOW, IZDATEL'STVO NAUKA, 1965, P. 70-74. IN RUSSIAN.
Publ. Date: 650000 Pages: 5 Language: RU (Russian)
Category code: 04 (biosciences)
Controlled terms: *ACCELERATION STRESS /*ANGULAR ACCELERATION /*HUMAN TOLERANCE /*PHYSIOLOGICAL RESPONSE / ACCELERATION / ANGULAR / BIOLOGICAL / EFFECT / HUMAN / MEDICINE / PHYSIOLOGY / RESPONSE / SPACE / STRESS /BIOL/ / TOLERANCE /BIOL/ /

Quest Accession Number : 63N11793
63N11793# NASA STAR Technical Report Issue: 04
(Thrombopenia following abrupt acceleration and impact)
(AA)TAYLOR, E. R.
Corp. Source: Aerospace Medical Div. Aeromedical Research Lab. (6571st), Holloman AFB, N. Mex. (AG575685)
ARL-TDR-62-30 AEROSPACE MEDICAL DIV., AEROMEDICAL RESEARCH LAB. /6571ST/, HOLLOMAN AFB, N. MEX. THROMBOCYTOPENIA FOLLOWING ABRUPT DECELERATION. A PRELIMINARY COMMUNICATION ELLIS R. TAYLOR DEC. 1962 17P 12 REFS /ARL-TDR-62-30/ Publ. Date: 621200 Pages: 17 Language: 00
Category code: 16 (masers)
Controlled terms: *BLOOD /*HUMAN BODY /*IMPACT /* PHYSIOLOGICAL ACCELERATION /*THROMBOPENIA / ACCELERATION / COUNT / DECELERATION / DECREASE / FACE / FORWARD / HUMAN / ONSET / PLATELET / POST / PROGRESSION / RATE / SEVERITY / SLED / SUBJECT / TEST /

Quest Accession Number : 62N10967
62N10967*# NASA STAR Technical Report Issue: 04
(The dynamic model - an engineering approach to the problem of tolerance to abrupt accelerations)
(AA)SHAPLAND, D. J.
Corp. Source: Stanley Aviation Corp., Denver, Colo. (S0463044)
SAC-59 Contract: NASR-37 STANLEY AVIATION CORP., DENVER, COLO. THE DYNAMIC MODEL - AN ENGINEERING APPROACH TO THE PROBLEM OF TOLERANCE TO ABRUPT ACCELERATIONS. DAVID J. SHAPLAND. <1961< 21 P. 7 REFS. /SAC-59/ /NASA CONTRACT NASR-37/ OTS- PH $2.60, MI $0.83. Publ. Date: 610000 Pages: 21 Language: 00
Category code: 16 (masers)
Controlled terms: *ACCELERATION /*DYNAMIC MODEL /*HUMAN PERFORMANCE /*HUMAN TOLERANCE /*PHYSIOLOGICAL ACCELERATION / AIRCRAFT / ANALOG / AXIS / COEFFICIENT / COMPUTER / DAMPING / DEFORMATION / DEGREE OF FREEDOM / DIGIT / DURATION /

design conditions and criteria as well. Volume 3 contains information on the design of aircraft structures and structural elements for improved crash survivability. Current requirements for structural design of U.S. Army aircraft pertaining to crashworthiness are discussed. Principles for crashworthy design are presented in detail for the landing gear and fuselage subject to a range of crash conditions, including impacts that are primarily longitudinal, vertical, or lateral in nature and those that involve more complicated dynamic conditions, such as rollover. Analytical methods for evaluating structural crashworthiness are described.
GRA

Category code: 03 (air transportation/safety)

Controlled terms: *AERONAUTICAL ENGINEERING /*AIRCRAFT DESIGN /*AIRFRAMES /*CRASHES /*DYNAMIC RESPONSE /*FLIGHT TESTS /*STRUCTURAL DESIGN / AIRCRAFT STRUCTURES / STRUCTURAL DESIGN CRITERIA / SYSTEMS ENGINEERING /

Quest Accession Number : 80N32358

80N32358# NASA STAR Technical Report Issue: 23

Aircraft crash survival design guide. Volume 4: Aircraft seats, restraints, litters, and padding / Final Report, Sep. 1977 - Feb. 1980

(AA)DESJARDINS, S. P.; (AB)LAANANEN, D. H.

Corp. Source: Simula, Inc., Tempe, Ariz. (SL704970) A2024546

AD-A088441; TR-7822-VOL-4; USARTL-TR-79-22D Contract: DAAJ02-77-C-0021; DA PROJ. 1L1-62209-AH-76 Publ. Date: 800600 Pages: 275 refs 0 (Revised) Language: EN (English) Avail.: NTIS HC A12/MF A01

This five volume document has been assembled to assist design engineers with the development of crashworthy U.S. Army aircraft. The five volumes of the Aircraft Crash Survival Design Guide cover the following topics: Volume 1 - Design Criteria and Checklists; Volume 2 - Aircraft Crash Environment and Human Tolerance: Volume 3 - Aircraft Structural Crashworthiness; Volume 4 - Aircraft Seats, Restraints, Litters, and Padding; Volume 5 - Aircraft Postcrash Survival. This volume (Volume 4) contains information on aircraft seats, litters, personnel restraint systems, and hazards in the occupant's immediate environment. Requirements for design of seats, litters, and restraint systems are discussed, as well as design principles for meeting these requirements and testing for verification that the systems perform as desired. Energy absorbing devices for use in seat are described, as are various types of cushions. Delethalization of cockpit and cabin interiors is discussed, including the use of protective padding and the design of controls for prevention of injury. Finally, computerized methods of analysis for evaluation of seats, restraints, and the occupant's immediate environment are presented.
GRA

Category code: 03 (air transportation/safety)

Controlled terms: *AIRCRAFT ACCIDENTS /*AIRCRAFT SURVIVABILITY /*FLIGHT SAFETY /*HARNESSES /*SEAT BELTS / ENERGY ABSORPTION / HUMAN FACTORS ENGINEERING / IMPACT RESISTANCE / SAFETY DEVICES /

Quest Accession Number : 96033384
A96-12346 AEROPLUS Issue: 9601
Design and testing of passenger seats for crash survival
Author(s): Brehaut, Wilfred H., Jr. (General Dynamics Corp., Convair Div., San Diego, CA)
Source Info: IN:Aircraft crashworthiness (A96-12340 01-03), Warrendale, PA, Society of Automotive Engineers, Inc., 1995, p. 41-44
Journal Announcement: IAA9601
Publisher: Society of Automotive Engineers, Inc., Warrendale, PA
Country of Publication: United States
Publication Year/Date: 1995; 950000
Document Type: REPRINT
Language: English
This paper defines a survivable crash and then describes the typical passenger seat available at the beginning of the jet age. The ground rules established at General Dynamics/Convair for the passenger seat to be used in the 880 and 990 series aircraft are enumerated. The static and dynamic testing of these seats is outlined, and the future direction of seat design and testing is speculated upon.
Classification: 03 (AIR TRANSPORTATION/SAFETY)
Controlled Term(s): PASSENGER AIRCRAFT / AIRCRAFT ACCIDENTS / SURVIVAL / SEATS / STRUCTURAL DESIGN / IMPACT TESTS / CRASHWORTHINESS

Quest Accession Number : 95N34378
95N34378# NASA STAR Technical Report Issue: 12
OH-58 pilot display unit (PDU) simulated crash tests / Final Report
(AA)HALEY, JOSEPH L., JR.; (AB)MCENTIRE, B. J.
Corp. Source: Army Aeromedical Research Lab., Fort Rucker, AL. (AY826435)
AD-A294049; USAARL-95-10 Contract: DA PROJ. 301-62787-A-878 Publ. Date: 941200 Pages: 54 Language: EN (English) Avail: CASI HC A04/MF A01
The pilot display unit (PDU) is designed to be placed directly in front of the pilot's eyes in the OH-58 helicopter to provide targeting and a missile status display. The location and the 7-pound mass of the unit creates a potentially hazardous head impact surface. In order to determine the degree of the hazard, a damaged OH-58 cockpit section was exposed to five survivable simulated crashes of moderate to severe impact vectors with an instrumented dummy pilot in the right seat behind the PDU. The cockpit floor was exposed to crash force up to 8 G in the vertical (z) axis and 19 G along the longitudinal (x) axis with velocity changes of 24 fps and 36 fps, respectively. These exposures did not exceed acceptable levels of human tolerance for neck and head forces when a properly fitted flight helmet was worn so that impact occurred on the helmet and not the head.
DTIC
Category code: 54 (man-system technology/life support)
Controlled terms: *CRASHES /*DISPLAY DEVICES /*FLIGHT CLOTHING /*HAZARDS /*HELMETS /*INJURIES /*OH-58 HELICOPTER / AIRCRAFT SAFETY / COCKPITS / HEAD (ANATOMY) / NECK (ANATOMY) / TOLERANCES (PHYSIOLOGY) /

Quest Accession Number : 94N33749
94N33749* NASA STAR Technical Report Issue: 10
Crash impact survival in light planes / (Videotape)
Corp. Source: National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH. (ND315753)
NASA-TM-109799; NONP-VT-94-12927 Publ. Date: 940000 Pages: 0 Videotape: 7 min. 45 sec. playing time, in color, with sound Language: EN (English) Avail: CASI VHS A01/BETA A22

This video explains the effects on aircraft and passengers of light plane crashes. The explanation is provided through the use of simulated light planes and dummies.
CASI

Category code: 03 (air transportation/safety)
Controlled terms: *AIRCRAFT ACCIDENTS /*CIVIL AVIATION /* CRASHES /*GENERAL AVIATION AIRCRAFT /*LIGHT AIRCRAFT /* PASSENGERS / AIRCRAFT SAFETY / CRASHWORTHINESS / DUMMIES / SURVIVAL /

Quest Accession Number : 92U05263
EAD Conference Paper NN=EE92U03030-034
Helicopter crash survival at sea: United States Navy/Marine Corps experience 1977-1990
Barker, C. O. ; Yacavone, W. ; Borowsky, M. S. ; Williamson, D. W.
Naval Safety Center, Norfolk, VA. (NT252649)
In AGARD, Aircraft Accidents: Trends in Aerospace Medical Investigation Techniques 8 p (SEE NN=EE92U03030) pp. 8 PD: 920900 Language: ENGLISH
Avail.: ESA-IRS, unrestricted distribution
The U.S. Navy/Marine Corps (USN) experience with helicopter class A water mishaps for the period from 1977 to 1990 is examined. There were 137 helicopter class A flight mishaps over water during this period with an overall survival rate of 83% in survivable water crashes. During this period, the USN developed several programs to improve survivability. The helicopter Water Survival Training Device (WSTD or 9-D-5 device) was instituted in 1982. The Helicopter Emergency Escape Device System (HEEDS) and the Helicopter Emergency Lighting System (HEELS) were implemented in 1987. The question of whether or not these programs have improved survival since their implementation is addressed and the types of operational problems encountered with these devices are reviewed. The results indicate that the WSTD and HEEDS may have contributed to the statistically significant improved survival seen among Navy aircrew in night crashes. They may have also contributed to the improvement (not satistically significant) in survival among passengers in night crashes. The data were inconclusive with respect to the effects of HEELS because of its not being implemented throughout the fleet. Operational problems with these devices were minor and the benefits of each program far outweigh any risks. In night crashes aircrew had significantly higher likelihood of survival than passengers who were essentially untrained occupants. Other factors, in addition to the devices studied, may have also affected survival probabilities.
Subject Category: 03 (AIR TRANSPORTATION/SAFETY)
Controlled terms: *AIRCRAFT ACCIDENTS /*ARMED FORCES (UNITED STATES) /*DITCHING (LANDING) /*ESCAPE SYSTEMS /* HELICOPTERS /*MORTALITY /*SURVIVAL / ACCIDENT INVESTIGATION / CRASHES / EDUCATION / FLIGHT CREWS / NIGHT FLIGHTS (AIRCRAFT) / PASSENGERS / STATISTICAL ANALYSIS /

Quest Accession Number : 90N22549
90N22549# NASA STAR Technical Report Issue: 16
Aircraft crash survival design guide. Volume 5: Aircraft postcrash survival / Final Report, Sep. 1986 - Aug. 1989
(AA)JOHNSON, N. B.; (AB)ROBERTSON, S. H.; (AC)HALL, D. S.
Corp. Source: Simula, Inc., Phoenix, AZ. (SL704492)
AD-A218438; USAAVSCOM-TR-89-D-22E-VOL-5 Contract: DAAJ02-86-C-0028 Publ. Date: 891200 Pages: 219 (Revised)
Language: EN (English) Avail: NTIS HC A10/MF A02
This five-volume publication was compiled to assist design engineers in understanding the design considerations associated with the development of crash-resistant U.S. Army aircraft. A collection of available information and data pertinent to aircraft crash resistance is presented, along

with suggested design conditions and criteria. The five volumes of the Aircraft Crash Survival Design Guide cover the following topics: Design Criteria and Checklists; Aircraft Design Crash Impact Conditions and Human Tolerance; Aircraft Structural Crash Resistance; Aircraft Seats, Restraints, Litters and Cockpit/Cabin Delethalization; and Aircraft Postcrash Survival. This volume (Volume 5) contains information on the aircraft postcrash environment and design techniques that can be used to reduce postcrash hazards. Topics include the postcrash fire environment, crashworthy fuel systems, ignition source control, fire behavior of interior materials, ditching survival, emergency escape, and crash locator beacons.
GRA

Category code: 03 (air transportation/safety)

Controlled terms: *AIRCRAFT ACCIDENTS /*AIRFRAME MATERIALS /*CRASHWORTHINESS /*FIRES /*FUEL SYSTEMS /*SURVIVAL / CHECKOUT / DITCHING (LANDING) / ENVIRONMENTAL CONTROL / ESCAPE SYSTEMS / HUMAN BEHAVIOR / IGNITION / SEATS / STRUCTURAL ANALYSIS / TOLERANCES (PHYSIOLOGY) /

Quest Accession Number : 90N22546

90N22546# NASA STAR Technical Report Issue: 16

Aircraft crash survival design guide. Volume 2: Aircraft design crash impact conditions and human tolerance / Final Report, Sep. 1986 - Aug. 1989

(AA)COLTMAN, J. W.; (AB)INGEN, C. V.; (AC)JOHNSON, N. B.; (AD)ZIMMERMAN, RICHARD E.

Corp. Source: Simula, Inc., Phoenix, AZ. (SL704492)

AD-A218435; USAAVSCOM-TR-89-D-22B-VOL-2 Contract: DAAJ02-86-C-0028 Publ. Date: 891200 Pages: 132 (Revised) Language: EN (English) Avail: NTIS HC A07/MF A01

This five-volume publication was compiled to assist design engineers in understanding the design considerations associated with the development of crash-resistant U.S. Army aircraft. A collection of available information and data pertinent to aircraft crash resistance is presented, along with suggested design conditions and criteria. The five volumes of the Aircraft Crash Survival Design guide cover the following topics: Design Criteria and Checklists; Aircraft Design Crash Impact Conditions and Human Tolerance; Aircraft Structural Crash Resistance; Aircraft Seats, Restraints, Litters and Cockpit/Cabin Delethalization; and Aircraft Postcrash Survival. This volume (Volume 2) contains information on the aircraft crash environment, human tolerance to impact, occupant motion during a crash, human anthropometry, and crash test dummies, all of which serves as background for the design information presented in the other volumes.
GRA

Category code: 03 (air transportation/safety)

Controlled terms: *AIRCRAFT ACCIDENTS /*AIRCRAFT DESIGN /* CRASH LANDING /*CRASHWORTHINESS /*IMPACT LOADS /*IMPACT TOLERANCES /*TOLERANCES (PHYSIOLOGY) / AIRFRAMES / ANTHROPOMETRY / BIODYNAMICS / CHECKOUT / HUMAN TOLERANCES / LANDING LOADS / SEATS / STRUCTURAL ANALYSIS / SURVIVAL /

Quest Accession Number : 90N22545
90N22545# NASA STAR Technical Report Issue: 16
Aircraft crash survival design guide. Volume 1: Design criteria and checklists / Final Report, Sep. 1986 - Aug. 1989
(AA)ZIMMERMAN, RICHARD E.; (AB)MERRITT, NORMAN A.
Corp. Source: Simula, Inc., Phoenix, AZ. (SL704492)
AD-A218434; USAAVSCOM-TR-89-D-22A-VOL-1 Contract: DAAJ02-86-C-0028 Publ. Date: 891200 Pages: 217 (Revised)
Language: EN (English) Avail: NTIS HC A10/MF A02
This five-volume publication was compiled to assist design engineers in understanding the design considerations associated with the development of crash-resistant U.S. Army aircraft. A collection of available information and data pertinent to aircraft crash resistance is presented, along with suggested design conditions and criteria. The five volumes of the Aircraft Crash Survival Design Guide cover the following topics: Design Criteria and Checklists; Aircraft Design Crash Impact Conditions and Human Tolerance; Aircraft Structural Crash Resistance; Aircraft Seats, Restraints, Litters and Cockpit/Cabin Delethalization; and Aircraft Postcrash Survival. This volume (Volume 1) contains concise criteria drawn from Volumes 2 through 5, supplemented by checklists intended to assist designers in implementing the criteria.
GRA
Category code: 03 (air transportation/safety)
Controlled terms: *AIRCRAFT ACCIDENTS /*AIRCRAFT DESIGN /*CRASHWORTHINESS /*DESIGN ANALYSIS /*FUEL SYSTEMS /*SURVIVAL / AERONAUTICAL ENGINEERING / AIRFRAMES / ANTHROPOMETRY / CHECKOUT / CRASHES / CUSHIONS / EMERGENCIES / ESCAPE SYSTEMS / FIRES / SEATS / STRUCTURAL ANALYSIS / TOLERANCES (PHYSIOLOGY) /

Quest Accession Number : 84N26584
84N26584# NASA STAR Conference Paper Issue: 17
Crash Position Indicator/Crash Survival Flight Data Recorder (CPI/CSFDR): Ejectable versus nonejectable
(AA)WATTERS, D. M.
Corp. Source: Naval Air Test Center, Patuxent River, Md. (NO894573)
In DFVLR Proc. of 12th Symp. on Aircraft Integrated Data Systems p 509-534 (SEE N84-26565 17-01). Publ. Date: 840200 Pages: 26 refs 0 Language: EN (English) Avail.: NTIS HC A25/MF A01
The use by carrier aircraft of nonejectable, and by military aircraft of both ejectable and nonejectable crash position indicator/crash survival flight data recorder/crash survival cockpit voice recorder (CPI/CSFDR/CSCVR) systems is discussed. The relevance of aircraft mission, acquisition and maintenance costs, complexity, reliability, record survivability, weight, volume, and power are considered. Ejectable CPI/CSFDR/CSCVR systems should be used on aircraft that operate over water. All other aircraft could use either ejectable or nonejectable systems.
Author (ESA)
Category code: 06 (aircraft instrumentation)
Controlled terms: *CRASHWORTHINESS /*EJECTION /*FLIGHT RECORDERS /*RADIO DIRECTION FINDERS / AIRCRAFT ACCIDENT INVESTIGATION / EQUIPMENT SPECIFICATIONS / JETTISONING /

Quest Accession Number : 81N16997
81N16997# NASA STAR Technical Report Issue: 08
Aircraft crash survival design guide. Volume 1: Design criteria and checklists, revision / Final Report
(AA)DESJARDINS, S. P.; (AB)LAANANEN, D. H.; (AC)SINGLEY, G. T., III
Corp. Source: Simula, Inc., Tempe, Ariz. (SL704970) A2024546
AD-A093784; TR-7927; USARTL-TR-79-22A Contract: DAAJ02-77-C-0021; DA PROJ. 1L1-62209-AH-79 Publ. Date: 801200 Pages: 272 refs 0 Language: EN (English) Avail.: NTIS HC A12/MF A01

This five-volume document has been assembled to assist design engineers in understanding the problems associated with the development of crashworthy U. S. Army aircraft. Contained herein are not only a collection of available information and data pertinent to aircraft crashworthiness but suggested design conditions and criteria as well. The five volumes of the Aircraft Crash Survival Design Guide cover the following topics: Volume 1 - Design Criteria and Checklists; Volume 2 - Aircraft Crash Environment and Human Tolerance; Volume 3 - Aircraft Structural Crashworthiness; Volume 4 - Aircraft Seats, Restraints, Litters, and Padding; and Volume 5 - Aircraft Postcrash Survival. This volume contains concise criteria drawn from Volumes 2 - 5, supplemented by checklists intended to assist designers in implementation of the criteria.
GRA

Category code: 03 (air transportation/safety)
Controlled terms: *AERONAUTICAL ENGINEERING /*AIRCRAFT ACCIDENTS /*AIRCRAFT SURVIVABILITY /*CRASHES / AIRCRAFT DESIGN / MILITARY AIRCRAFT /

Quest Accession Number : 90N26496
90N26496# NASA STAR Technical Report Issue: 20
Human factors: The human interface with aircraft interiors
(AA)CHAMBERS, RANDALL; (AB)FERNANDEZ, JEFFREY; (AC)NANDIGAM, SRIKANTH; (AD)PALANISWAMY, VANKATESH
Corp. Source: Wichita State Univ., KS. (W0802171) National Inst. for Aviation Research.
NIAR-90-18 Publ. Date: 900600 Pages: 29 Language: EN (English) Avail: NTIS HC A03/MF A01

The pilot, crew, and passengers interface with the aircraft's interior, its operational performance, its protective features and crash worthiness, its utilization during linear and angular accelerations and decelerations, and its management during crisis of a severe stress of impact and fire. Human factors considerations enter into the measurement and evaluation of crashworthiness performance, especially in the design criteria for seats, seat belts, shoulder harness, air bags, floors, and wall structures. Human factors considerations and design criteria also enter into the measurement and evaluation of performance, especially in crisis management and control, and performance of flight crew and passengers during fire, escape, depressurization, and other emergency situations. The human interface for protection in Gx accelerations and decelerations, and in Gy and Gz, have important design criteria for seats, back angle, shoulder straps and seat belts, dynamic and static supports, for head, neck, and torso. Body size and position for adults and for children require special considerations within acceleration fields produced within varying transportation systems. Subjective judgments of ride quality, comfort, and well-being are important in the human use of restraints and other interior protective components. Similarily, physiological indices and specific body distortions during deceleration, impact and burn provide important design criteria. Human use of controls and displays during emergency preparations and escape add specific design criteria and requirements for aircraft interior development.
Author

Category code: 54 (man-system technology/life support)
Controlled terms: *AIR BAG RESTRAINT DEVICES /*AIRCRAFT COMPARTMENTS /*COMFORT /*CONSTRAINTS /*CRASHWORTHINESS /*EMERGENCIES /*FLIGHT CREWS /*HARNESSES /*HUMAN FACTORS ENGINEERING /*PASSENGERS /*RIDING QUALITY /*SEAT BELTS /*SEATS / CHILDREN / DECELERATION / DESIGN ANALYSIS / PHYSIOLOGY / PRESSURE REDUCTION / STRAPS / TORSO / TRANSPORTATION /

Quest Accession Number : 79A52694
79A52694*# NASA IAA Conference Paper Issue: 23
NASA/FAA general aviation crash dynamics program - An update
(AA)HAYDUK, R. J.; (AB)THOMSON, R. G.; (AC)CARDEN, H. D.
Author Affiliation: (AC)(NASA, Langley Research Center, Hampton, Va.)
Corp. Source: National Aeronautics and Space Administration. Langley Research Center, Hampton, Va. (ND210491)

International Society of Air Safety Investigators, Annual Seminar, Montreal, Canada, Sept. 24-27, 1979, Paper. 12 p.,
Publ. Date: 790900 Pages: 12 refs 15 Language: EN (English)

Work in progress in the NASA/FAA General Aviation Crash Dynamics Program for the development of technology for increased crash-worthiness and occupant survivability of general aviation aircraft is presented. Full-scale crash testing facilities and procedures are outlined, and a chronological summary of full-scale tests conducted and planned is presented. The Plastic and Large Deflection Analysis of Nonlinear Structures and Modified Seat Occupant Model for Light Aircraft computer programs which form part of the effort to predict nonlinear geometric and material behavior of sheet-stringer aircraft structures subjected to large deformations are described, and excellent agreement between simulations and experiments is noted. The development of structural concepts to attenuate the load transmitted to the passenger through the seats and subfloor structure is discussed, and an apparatus built to test emergency locator transmitters in a realistic environment is presented.
A.L.W.

Category code: 03 (air transportation/safety)

Controlled terms: *AIRCRAFT SAFETY /*CRASH LANDING /* GENERAL AVIATION AIRCRAFT /*IMPACT DAMAGE /*SEATS /*TEST FACILITIES / AIRCRAFT COMPARTMENTS / AIRCRAFT STRUCTURES / COMPOSITE STRUCTURES / COMPUTERIZED SIMULATION / GRAPHS (CHARTS) / NASA PROGRAMS / STRUCTURAL DESIGN CRITERIA /

Quest Accession Number : 69A41133

69A41133# NASA IAA Issue: 22

Design for safety - Third generation and ahead. (Safety standards for DC 10 aircraft, considering cockpit design, hydraulic, electric power, autoland and direct lift control systems, structural safety and crash worthiness)

(AA)HEIMERDINGER, A. G.

(AA)/MCDONNELL DOUGLAS CORP., ST. LOUIS, MO./.

FLIGHT SAFETY FOUNDATION, INC.,, ARLINGTON, VA.,, Publ. Date: 680000 Pages: 5 IN- FLIGHT SAFETY FOUNDATION, ANNUAL INTERNATIONAL AIR SAFETY SEMINAR, 21ST, ANAHEIM, CALIF., OCT. 8-11, 1968, TECHNICAL SUMMARY. P. 44-48. /A69-41127 22-02/. Language: EN (English)

Category code: 02 (aircraft)

Controlled terms: *AIRCRAFT DESIGN /*AIRCRAFT SAFETY /*DC 10 AIRCRAFT /*SAFETY FACTORS /*STRUCTURAL RELIABILITY / AIRCRAFT HYDRAULIC SYSTEMS / AUTOMATIC LANDING CONTROL / AUXILIARY POWER SOURCES / COCKPITS / CONFERENCES / CRASHES / LIFT DEVICES /

Quest Accession Number : 66N39479
66N39479# NASA STAR Technical Report Issue: 24
Principles for improving structural crash worthiness for STOL and CTOL aircraft (Crash behavior analysis of STOL and CTOL AIRCRAFT)
(AA)AVERY, J. P.; (AB)REED, W. H., III
Corp. Source: Aviation Safety Engineering and Research, Phoenix, Ariz. (A9921291) AZ142325
AVSER-65-18; USAAVLABS-TR-66-39; AD-637133 Contract: DA-44-177-AMC-254/T/ FT. EUSTIS, VA., ARMY AVIATION MATER. LABS., JUN. 1966 73 P REFS Publ. Date: 660600 Pages: 73 Language: EN (English) Avail.: NTIS
Category code: 02 (aircraft)
Controlled terms: *AIRCRAFT SAFETY /*CRASH /*STOL AIRCRAFT /*STRUCTURAL DESIGN / ABSORPTION / AIRFRAME / ANALYSIS / AVIATION / BEHAVIOR / DEFORMATION / ENERGY / IMPACT / INJURY / LONGITUDINAL / MASS / SHOCK / VERTICAL /

Quest Accession Number : 96N50693
96053804# NASA STAR Conference Paper Issue: 9623
CogScreen-Aeromedical Edition in the Assessment of the Head Injured Military Aviator
(AA)Moore, J. L.; (AB)Kay, G. G.
Author Affiliation: (AA)(Naval Aerospace Medical Inst., Pensacola, FL United States); (AB)(Naval Aerospace Medical Inst., Pensacola, FL United States)
Corp. Source: Naval Aerospace Medical Inst., Pensacola, FL United States (NN868269)
Publ. Date: 19960401 Pages: 6p FRFR Language: English
Avail: CASI A02 Hardcopy/CASI A03 Microfiche
CogScreen-Aeromedical Edition (CogScreen-AE) is a computer administered and scored cognitive screening instrument designed to rapidly assess deficits or changes in attention, immediate and short-term memory, spatial-perceptual functions, calculation skills, reaction time, simultaneous information processing, and executive functions. The test was designed to detect subtle changes in cognitive functioning, which left un-noticed may result in poor pilot judgment or slow reaction time in critical operational situations. Normative data have been collected on over 800 commercial airline pilots and an equal number of military aviators. This paper will focus on applications of CogScreen-AE in the evaluation of head injured military aviation personnel. The CogScreen test results from a group of 24 mild to severely injured military aviators who were tested up to 90 months following head injury, and five of whom received serial evaluations, are presented. The results of the serial evaluations of five head injured military aviators are also discussed. Results demonstrate the sensitivity of the test to initial injury severity and recovery of function. The combination of conventional neuropsychological instruments and CogScreen-AE may expedite the return of head injured aviators to flying duties and actual control of aircraft.
Derived from text
Category code: 52 (aerospace medecine)
Controlled terms: *AEROSPACE MEDICINE /*AIRCRAFT PILOTS /* INJURIES /*HEAD (ANATOMY) / COGNITIVE PSYCHOLOGY / COMMERCIAL AIRCRAFT / DATA PROCESSING / FLYING PERSONNEL / PSYCHOLOGICAL TESTS / JUDGMENTS /

Quest Accession Number : 96U03587
EAD Conference Paper NN=EE96U05380-010
CogScreen-Aeromedical Edition in the assessment of the head injured military aviator
Moore, J. L. ; Kay, G. G.
Naval Aerospace Medical Inst., Pensacola, FL. (NN868269)
In AGARD, Neurological Limitations of Aircraft Operations: Human Performance Implications p 13,1-13,5 (SEE NN=EE96U05380) pp. 5 PD:960400 Language: ENGLISH
Avail.: ESA-IRS, unrestricted distribution
The CogScreen-Aeromedical Edition is a computer administered and stored cognitive screening instrument designed to rapidly assess deficits or changes in attention, immediate and short term memory, spatial-perceptual functions, calculation skills, reaction time, simultaneous information processing and executive functions. The test was designed to detect subtle changes in cognitive functioning that would, if left undetected, lead to poor pilot judgement or slow reaction times in critical operational situations. The applications of the system in the evaluation of military aviation personnel with head injuries are described. Test results from a group of injured aviators are presented and discussed. The results demonstrate the sensitivity of the test to the initial injury sensitivity and the recovery function.
Subject Category: 52 (AEROSPACE MEDICINE)
Controlled terms: *PILOT PERFORMANCE /*PILOT SELECTION /* HEAD (ANATOMY) /*INJURIES / COGNITION / MENTAL PERFORMANCE / WORKLOADS (PSYCHOPHYSIOLOGY) / REACTION TIME /

Quest Accession Number : 95A68894

95A68894 NASA IAA Journal Article Issue: 05

Regional lung hematocrit variation and assessment of acute lung injury

(AA)KANAZAWA, MINORU; (AB)HASEGAWA, NOKI; (AC)URANO, TESTUYA; (AD)SAYAMA, KOICHI; (AE)TASAKA, SADATOMO; (AF)SAKAMAKI, FUMIO; (AG)NAKAMURA, HIDETOSHI; (AH)WAKI, YASUHIRO; (AI)TERASHIMA, TAKESHI; (AJ)FUJISHIMA, SEITARO

Author Affiliation: (AA)Keio Univ., Tokyo, Japan; (AB)Keio Univ., Tokyo, Japan; (AC)Keio Univ., Tokyo, Japan; (AD)Keio Univ., Tokyo, Japan; (AE)Keio Univ., Tokyo, Japan; (AF)Keio Univ., Tokyo, Japan; (AG)Keio Univ., Tokyo, Japan; (AH)Keio Univ., Tokyo, Japan; (AI)Keio Univ., Tokyo, Japan; (AJ)Keio Univ., Tokyo, Japan

HTN-95-A0111 Journal of Applied Physiology (ISSN 8750-7587), vol. 77, no. 2, August 1994, p. 567-573

Publ. Date: 940800 Pages: 7 Language: EN (English)

Estimating blood content in the lung remains a key step in calculating lung water volume and microvascular permeability. We studied the effect of regional lung hematocrit (Hct) variation on assessment of acute lung injury. Escherichia coli endotoxin was administered in guinea pigs intravenously. Lung injury was evaluated by measuring the wet-to-dry weight ratio (W/D) and transvascular I-125-labeled albumin leakage for 3 h (tissue-to-plasma I-125-albumin ratio (T/P)) in five tissue samples from each animal. Residual blood content was corrected using either Cr-51-red blood cells as a blood cell marker, (99m)Tc-albumin as a plasma marker, or both, injected 10 min before the guinea pigs were killed. Lung Hct, estimated from the marker counts of lung and peripheral blood samples, was lower than peripheral blood Hct; intraindividual variation, represented by the standard deviation in each subject, was 0.024 +/- 0.015 for the control group (coefficient of variation 8.0 +/- 5.1%) and 0.026 +/- 0.013 for the endotoxin group (coefficient of variation 8.5 +/- 4.1%). Uncorrected W/D for residual blood content was greater than the corrected W/D. (99m)Tc-albumin correction gave values closer to the W/D corrected by both markers. T/P corrected by (99m)Tc-albumin showed smaller data variations than the values obtained with Cr-51-red blood cell correction, which was affected by variations in lung Hct. We recommend using a plasma marker to correct for blood content in assessing acute lung injury by W/D and T/P. Author (Herner)

Category code: 51 (life sciences)

Controlled terms: *ENDOTOXINS /*INJURIES /*LUNGS /* MOISTURE CONTENT /*PERMEABILITY /*PULMONARY CIRCULATION /* TECHNETIUM / ALBUMINS / ESCHERICHIA / GUINEA PIGS / HEMATOCRIT RATIO / RESPIRATORY PHYSIOLOGY / WATER BALANCE /

Quest Accession Number : 95055508
A95-23877 AEROPLUS Issue: 9505
Six degree of freedom (6 DOF) modeling as an analytical tool for prediction of small air crew injury potential
Author(s): Quartuccio, John J. (U.S. Navy, Naval Air Warfare Center, Warminster, PA); Nichols, Jeffrey P. (U.S. Navy, Naval Air Warfare Center, Warminster, PA); Marquette, Thomas J. (U.S. Navy, Naval Air Warfare Center, Warminster, PA)
Source Info: IN:SAFE Association, Annual Symposium, 32nd, Reno, NV, Oct. 10-12, 1994, Proceedings (A95-23851 05-54), Cottage Grove, OR, SAFE Association, 1994, p. 175-183
Journal Announcement: IAA9505
Publisher: SAFE Association, Cottage Grove, OR
Country of Publication: United States
Publication Year/Date: 1994; 940000
Document Type: CONFERENCE VOLUME - ANALYTIC
Language: English
With the Navy's recent expansion of the air crew population to include a greater percentage of aviators, both male and female, the accommodation of small aircrew has become an important issue. The GRU-7 ejection seat currently used in the F-14A aircraft was designed and test qualified to be used by 140 to 204 lb male aviators. This seat has not been test qualified for fiight by air crew smaller than a 140 lb male. Such air crew may be subjected to higher risk of injury in the event of an ejection. This presentation reviews the results of an effort conducted by the Naval Air Warfare Center, Aircraft Division, Warminster to quantify the risk of injury to small aviators in GRU-7 ejections.
Classification: 54 (MAN-SYSTEM TECHNOLOGY/LIFE SUPPORT)
Controlled Term(s): DEGREES OF FREEDOM / INJURIES / F-14 AIRCRAFT / FLIGHT CREWS / ANTHROPOMETRY / ROCKET ENGINES / NAVY / AERODYNAMIC LOADS / DRAG CHUTES

Quest Accession Number : 94N13972
94N13972# NASA STAR Technical Report Issue: 02
An assessment of the potential for neck injury due to padding of aircraft interior walls for head impact protection / Final Report
(AA)ARMENIA-COPE, R.; (AB)MARCUS, J. H.; (AC)GOWDY, R. V.; (AD)DEWEESE, R. L.
Corp. Source: Civil Aeromedical Inst., Oklahoma City, OK. (CP949112)
DOT/FAA/AM-93/14 Publ. Date: 930800 Pages: 13
Language: EN (English) Avail: CASI HC A03/MF A01
This report describes a short test program to assess the potential for neck injury induced by placing padding on the interior walls of an aircraft cabin to reduce the possibility of a head injury during a crash. Such padding is a possible mechanism of achieving the heightened impact protection requirements adopted by the Federal Aviation Administration in 1988. The report reviews the literature on impact induced neck injury, and reports neck injury criteria developed and reported by others. The type of test device to use with the neck injury criteria is also discussed. Using the reported neck injury criteria, and a Hybrid 3 test dummy with neck instrumentation, the testing program found that neck injury, with one exception, was not likely in either the tested pad or unpadded case. The one exception was neck extension injuries for which both the unpadded and padded tests exceeded the injury criteria. The tested pad, in comparison to the unpadded case, substantially decreased the neck extension moment, implying a reduction in neck injury risk.
Author (revised)
Category code: 54 (man-system technology/life support)
Controlled terms: *AIRCRAFT ACCIDENTS /*AIRCRAFT COMPARTMENTS /*CRASHES /*CUSHIONS /*DUMMIES /*HUMAN TOLERANCES /*IMPACT RESISTANCE /*IMPACT TESTS /*INJURIES /* NECK (ANATOMY) /*PROTECTION /*WALLS / CRASHWORTHINESS / RISK /

Quest Accession Number : 93A13720
93A13720 NASA IAA Journal Article Issue: 02
Identification of degree of head injury caused by impact loads in dog and rabbit
(AA)WU, GUIRONG
Author Affiliation: (AA)(Inst. of Space Medico-Engineering, Beijing, China)
Space Medicine & Medical Engineering (ISSN 1002-0837), vol. 3, no. 4, 1990, p. 261-266. Publ. Date: 900000
Pages: 6 refs 11 Language: CH (Chinese)
Impacts on occiputs of dogs and rabbits were given by simple impact equipment to observe changes of CPK in cerebrospinal fluid and intracranial pressure with different degrees of head injury. The results indicate that CPK and intracranial pressure increase exponentially with the degree of head injury. It seems that they might serve as indices in judging the degree of animal head injury. Special behavioral and psychological responses were also observed in the animals developing brain concussion. They could serve as signs for preliminary diagnosis.
Author

Category code: 51 (life sciences)
Controlled terms: *BRAIN CIRCULATION /*IMPACT LOADS /* INJURIES /*PHYSIOLOGICAL RESPONSES / DOGS / RABBITS / RADIOIMMUNOASSAY /

Quest Accession Number : 93N11285
93N11285# NASA STAR Conference Paper Issue: 02
Mechanisms of immune failure in burn injury
(AA)SPARKES, BRIAN G.
Corp. Source: Defence and Civil Inst. of Environmental Medicine, North York (Ontario). (DG869614)
In AGARD, Allergic, Immunological and Infectious Disease Problems in Aerospace Medicine 12 p (SEE N93-11283 02-52).
Publ. Date: 920400 Pages: 12 Language: EN (English)
Avail: CASI HC A03/MF A03

The burden on military medical services in handling burn casualties is daunting as all physiological systems will become affected. Severe burns in a battlefield setting have a very low salvage rate, to a great degree because of the immune failure which invariably develops. Evaluations of responses of lymphocytes taken from burn patients over several weeks following the burn (greater than 30 percent TBSA), have revealed that the immune failure which follows thermal injury involves T cell activation events. Interleukin 2, which is normally produced by activated T lymphocytes, is very poorly produced by cells cultivated in vitro taken from non-surviving patients, whereas some production continues, although at below normal levels, in patients who ultimately survive their injury. IL2 exogenously added to lymphocyte cultures enhances the proliferation of cells from surviving patients but gives no such help to cells from nonsurvivors. The TAC portion of the IL2 receptor (IL2R alpha), expressed on the T cell surface, appears to be responsible for this difference, as the number of lymphocytes able to express ILR2 alpha falls post-burn. A lipid protein complex (LPC) produced in skin by burning has been shown to inhibit the immune response in vivo and the growth of IL2-dependent lymphocytes in culture. Cerium nitrate, applied topically to the burn patient, is thought to fix the LPC in the burn eschar and prevents its entry into the circulation. In a study of 10 patients, bathed in cerium nitrate, some T lymphocyte activities were found to be in the normal range rather than suppressed. Such a treatment promises to be useful in improving chances of survival in severe burn injury.
Author

Category code: 52 (aerospace medecine)
Controlled terms: *BURNS (INJURIES) /*IMMUNITY /* IMMUNOLOGY /*LYMPHOCYTES /*MEDICAL SERVICES /*MILITARY OPERATIONS /*PHYSIOLOGICAL RESPONSES /*PHYSIOLOGY /*SURVIVAL / CASUALTIES / CERIUM COMPOUNDS / LIPIDS / NITRATES / PATIENTS / PROTEINS /

Quest Accession Number : 92A45947
92A45947 NASA IAA Journal Article Issue: 19
Analysis of the mechanism and protection of upper limb windblast flailing injury
(AA)ZHANG, YUN-RAN
Author Affiliation: (AA)(Institute of Space Medico-Engineering, Beijing, People's Republic of China)
Space Medicine & Medical Engineering (ISSN 1002-0837), vol. 5, no. 1, 1992, p. 19-24. In Chinese., Publ. Date: 920000 Pages: 6 refs 3 Language: CH (Chinese)
The mechanism of the upper limb windblast flailing injury of pilots during ejection was investigated analytically. The constraining equations for steady states were developed and were used to calculate the value of constraining force needed for the protection of the upper limb at steady-state ejection. Calculations of the lowest constraining forces needed for the upper limb, under the configuration of hands on the top of the thighs and hands on alternate firing handle showed that the optimal location to exert minimal constraining forces on upper limbs is close to the elbow joints and the carpus joints. The design of an arm-restraint plate and the optimum ejection attitude are discussed.
I.S.
Category code: 52 (aerospace medecine)
Controlled terms: *BLAST LOADS /*EJECTION INJURIES /*EJECTION SEATS /*LIMBS (ANATOMY) /*SAFETY DEVICES / FLIGHT CREWS / STEADY STATE /

Quest Accession Number : 92N30844
92N30844# NASA STAR Technical Report Issue: 21
Adapting the ADAM manikin technology for injury probability assessment / Final Report, 5 Jul. 1991 - 19 Feb. 1992
(AA)RADDIN, J. H., JR.; (AB)SCOTT, W. R.; (AC)BOMAR, J. B. ; (AD)SMITH, H. L.; (AE)BENEDICT, J. V.
Corp. Source: Biodynamic Research Corp., San Antonio, TX. (BO770470)
AD-A252332; AL-TR-1992-0062 Contract: F41624-91-C-6003 Publ. Date: 920219 Pages: 251 Language: EN (English) Avail: CASI HC A12/MF A03
An approach is presented for the general definition of regional injury human impact criteria with particular attention to the articulated ADAM test manikin and the escape environment. A review of literature and ejection injury data confirmed that injuries of greatest interest were those to the head, neck, thoracolumbar spine, and proximal extremities. A substantial literature review was pursued, demonstrating consistent findings of strain rate-dependent injury behavior over a wide range of injury types and body regions. Building upon previous work on the Dynamic Response Index, a comprehensive proposal is advanced for the conceptual definition of regional viscoelastic strain models for injury probability assessment. The proposed form for a head injury criterion assesses both translation and angular acceleration stress in terms of viscoelastic strain while also incorporating a means to account for their interaction. The neck criterion is based on a viscoelastic strain model of axial stress in association with shear and moment effects. The thoracolumbar

spine criterion also proposes an extension of the prior DRI approach to account for interacting effects of moments and shear stresses. Approaches for the proximal extremities are formulated in a similar fashion. An outline is proposed for quantitative formulation and validation of the concept.
GRA

Category code: 54 (man-system technology/life support)

Controlled terms: *ANGULAR ACCELERATION /*DYNAMIC RESPONSE /*EJECTION /*EJECTION SEATS /*HEAD (ANATOMY) /*INJURIES /*MODELS /*NECK (ANATOMY) /*PROBABILITY THEORY /*SPINE /*STRAIN RATE /*TECHNOLOGY ASSESSMENT / EVALUATION / IMPACT / PERFORMANCE TESTS / SHEAR STRESS /

Quest Accession Number : 92U05240

EAD Conference Paper NN=EE92U03030-011

Is axial loading a primary mechanism of injury to the lower limb in an impact aircraft accident?

Rowles, J. M. ; Brownson, P. ; Wallace, W. A. ; Anton, D. J. (Royal Air Force Inst. of Aviation Medicine, Farnborough (United Kingdom).)

Nottingham Univ. (United Kingdom). (N7525947) Dept. of Orthopaedic and Accident Surgery.

In AGARD, Aircraft Accidents: Trends in Aerospace Medical Investigation Techniques 8 p (SEE NN=EE92U03030) pp. 8 PD: 920900 Language: ENGLISH

Avail.: ESA-IRS, unrestricted distribution

Following the crash of a Boeing 737-400 aircraft on the motorway near Kegworth (England) on 8 Jan. 1989, it became apparent that a large number of pelvic and lower limb injuries were sustained by the survivors. Had there been a fire this would have severely hindered the ability of the occupants to escape. The mechanism of pelvic and lower limb injuries in impact accidents has been related to flailing of the limbs and axial loading of the femur. The validity of axial loading of the femur as a primary mechanisms of femoral fracture in an impact aircraft accident is questioned. Two methods of study were used to investigate the impact biomechanics of the pelvis and lower limb: clinical review and impact testing using anthropomorphic dummies. The study suggests that in the presence of intact occupant protection systems, bending of the femur over the front spar of passenger seats is the primary mechanisms of causation of femoral fractures. Occupant protection systems designed for civil aircraft should be modified to accommodate loading of the femur over the front of the seat.

Subject Category: 03 (AIR TRANSPORTATION/SAFETY)

Controlled terms: *AIRCRAFT ACCIDENTS /*AXIAL LOADS /*BIODYNAMICS /*IMPACT /*INJURIES /*LEG (ANATOMY) /*PELVIS / ANTHROPOMETRY / CLINICAL MEDICINE / CRASHES / DUMMIES / ENGLAND / IMPACT TESTS / SITTING POSITION /

Quest Accession Number : 90N25479
90N25479# NASA STAR Conference Paper Issue: 19
Measurement techniques, evaluation criteria and injury probability assessment methodologies developed for Navy ejection and crashworthy seat evaluations
(AA)FRISCH, GEORGE D.; (AB)KINKER, LAWRENCE E.; (AC)FRISCH, PAUL H.
Author Affiliation: (AC)(Applied Physics, Inc., Nanuet, NY.)
Corp. Source: Naval Air Development Center, Warminster, PA. (NO000154)
In AGARD, Neck Injury in Advanced Military Aircraft Environments 8 p (SEE N90-25459 19-52). Publ. Date: 900200
Pages: 8 Language: EN (English) Avail: NTIS HC A10/MF A02; Non-NATO Nationals requests available only from AGARD/Scientific Publications Executive
Head and neck injuries are of particular concern to Navy researchers and extensive programs were initiated to address head and neck response of both live human subjects and human analogs to crash impact forces. This concern was somewhat heightened by the apparently conflicting operational requirements of having canopy penetration as the principal means of ejection in several aircraft prototypes, coupled to the requirement of introducing night vision capability in attack aircraft. The latter will most probably lead to increased helmet volume, and possibly weight, which increases the probability of helmet canopy acrylic interaction during canopy penetration. Increased helmet weight and center of gravity shifts, together with altered helmet to head coupling, will certainly change head and neck response to even presumably safe exposure levels. In order to adequately parameterize head and neck response and relate the gathered data to known living human subject and cadaver data, both inertial response and load data must be obtained at well defined, anatomically correctable points. A modified Hybrid 3 type head and neck complex was developed, ballasted to be in compliance with Navy generated head and neck mass distribution parameters, and fully instrumented at the head center of gravity (CG), occipital condyles, and the base of the neck. The fully instrumented head and neck system was utilized to evaluated various helmet configurations and the effect on head and neck response with changes in helmet weight and geometry. Additionally, neck extension, compression, shear forces, and torques were obtained during dynamic ejection tests ranging from 0/0 to 720 KEAS. At the higher speeds, the effects of aerodynamic lift can be identified on the monitored neck compression-tension values. With such data, injury modalitiens and probabilities can be addressed in considerably greater detail than the present norm and the effectiveness of protective equipment established.
Author
Category code: 52 (aerospace medecine)
Controlled terms: *CANOPIES /*CRASHES /*DYNAMIC TESTS /* EJECTION SEATS /*HEAD (ANATOMY) /*HELMET MOUNTED DISPLAYS /* INJURIES /*PENETRATION /*PROBABILITY THEORY /*PROTOTYPES / ACRYLIC RESINS / ATTACK AIRCRAFT / CENTER OF GRAVITY / EJECTION / EXPOSURE / LOADS (FORCES) / MASS DISTRIBUTION / NIGHT VISION / TORQUE /

Quest Accession Number : 90A17428

90A17428 NASA IAA Conference Paper Issue: 05

Spinal response/injury assessment during various ejection and crash scenarios employing manikin based load and torque measurements

(AA)FRISCH, GEORG D.; (AB)MILLER, KENNETH; (AC)FRISCH, PAUL H.

Author Affiliation: (AB)(U.S. Navy, Naval Air Development Center, Warminster, PA); (AC)(Applied Physics, Inc., Nanuet, NY)

IN: Annual SAFE Symposium, 26th, Las Vegas, NV, Dec. 5-8, 1988, Proceedings (A90-17401 05-54). Newhall, CA, SAFE Association, 1989, p. 220-226., Publ. Date: 890000 Pages: 7 Language: EN (English)

Manikin-based instrumentation requirements have been standardized to include load measurements (compression, shear, torques) at the pelvic-lumbar spine junction, thoracic-cervical spine interface, and occipital condyles. A series of horizontal accelerator and ejection tower tests have been completed to establish baseline values for these measures under a variety of initial position and restraint configurations. For the head and neck system, the sensitivity of the resulting measured values to changes in head weight and center of gravity was also established. These data are the baseline values against which new helmet configurations (such as night vision) will be compared and from which relative safety assessments can be made. Spinal loads during dynamic ejection have also been obtained for a variety of airspeeds (0, 450 KEAS) and canopy penetration conditions. These baseline values demonstrate a highly improved technique to analyze and quantify canopy penetration severity and helmet lift forces during high 'Q' escape.
C.E.

Category code: 09 (research and support facilities (air))

Controlled terms: *CRASH INJURIES /*EJECTION INJURIES /* SPINAL CORD /*TORQUEMETERS / ACCELERATION (PHYSICS) / COMPRESSION LOADS / FLIGHT TESTS /

Quest Accession Number : 89A45340
89A45340 NASA IAA Journal Article Issue: 19
An evaluation of proposed causal mechanisms for `ejection associated` neck injuries
(AA)GUILL, FREDERICK C.; (AB)HERD, G. RONALD
Author Affiliation: (AB)(U.S. Navy, Crew Systems Div., Washington, DC)
Aviation, Space, and Environmental Medicine (ISSN 0095-6562), vol. 60, July 1989, p. A26-A47., Publl. Date: 890700 Pages: 22 refs 8 Language: EN (English)
Possible causal factors and mechanisms responsible for neck injuries associated with various phases of aircraft ejection (i.e., preejection, ejection through catapult boost, postboost, and postparachute opening) were identified using data from the data bank at the Naval Weapons Engineering Support Activity. The body motions and forces associated with through-the-canopy ejection are analyzed and the spectral range neck fractures and sprains/strains, and the ranges of their severity are examined. The relations between the severity of neck injury and the ejection speed, aircraft series, aircraft maneuver load and speed, the type of ejection seat, the factor of lost helmet, the body position, and the parachute opening shock are investigated. Evidence is presented that many of the reported neck injuries were the consequence of system malfunction.
I.S.
Category code: 52 (aerospace medecine)
Controlled terms: *AIRCRAFT /*AIRCRAFT ACCIDENTS /* EJECTION SEATS /*INJURIES /*NECK (ANATOMY) / BIODYNAMICS / FRACTURING / VERTEBRAE /

Quest Accession Number : 89A45339
89A45339 NASA IAA Journal Article Issue: 19
Mechanism of injury in aircraft accidents - A theoretical approach
(AA)HILL, I. R.
Author Affiliation: (AA)(RAF, Institute of Pathology and Tropical Medicine, Halton, England)
Aviation, Space, and Environmental Medicine (ISSN 0095-6562), vol. 60, July 1989, p. A18-A25., Publ. Date: 890700 Pages: 8 refs 29 Language: EN (English)
The mechanisms of injury produced in aircraft accidents are discussed. Consideration is given to the causes of injury, which include crushing within a collapsing airframe, entrapment within the wreckage, the absence or failure of restraint, impacts by loose objects, escape mishaps, and explosive decompression. Particular attention is given to the possibility of correlating the topography of a wound with its cause. It is shown that the injuruy production in aircraft accidents is a complex issue that cannot be easily resolved, because not all of the basic science is known, and even the principles are controversial. It is emphasized that the limiting factor in survivability may be the pathophysiological response of the biological system, and that this fact, combined with varying physiochemical properties of given tissues, may be the key factor to tolerance to injury.
I.S.

Category code: 52 (aerospace medecine)
Controlled terms: *AEROSPACE MEDICINE /*AIRCRAFT ACCIDENTS /*HUMAN PATHOLOGY /*INJURIES / BIODYNAMICS / BLASTS / CRUSHING / EJECTION SEATS / IMPACT DAMAGE / PRESSURE REDUCTION /

Quest Accession Number : 85N21976
85N21976# NASA STAR Technical Report Issue: 12
The clinical and radiological assessment of cervical injury, Annex A
Corp. Source: French Air Force, Paris. (F7184220)
In AGARD Rept. on the Working Group on the Clinical and Biomedical Evaluation of Trauma and Fatalities Associated with Aircrew Ejection and Crash p 34-66 (SEE N85-21969 12-52). Publ. Date: 841200 Pages: 33 refs 0 Language: EN (English) Avail.: NTIS HC A05/MF A01

The cervical spine is the most mobile portion of the spine. During trauma, this mobility is compounded by inertia forces at the skull and the presence of the spinal cord, which is less well protected here than in other portions of the spine. Injuries following ejection would seem to be unusual, but when they do occur may take a variety of forms: fracture dislocations, dislocations, severe strains. If these lesions are unstable, dramatic neurological complications may occur immediately or after some delay. The task of identifying factors of instability of a cervical lesion falls to the radiological examination. It should be recalled that radiological exploration of the whole spine, segment by segment, of any survivors is obligatory in the Armee de l'Air Francaise (French Air Force), following ejection or any accident involving the flight deck. The radiological examination of the cervical spine is difficult; it is based on the findings of the clinical examination of the subject and the plates are difficult to interpret. The initial radiological methods and incidences used (routine plates, tomograms and sometimes dynamic radiography) are considered. The more demanding secondary examinations, such as the scanner, myelogram or angiogram are not discussed.
Author

Category code: 52 (aerospace medecine)
Controlled terms: *CLINICAL MEDICINE /*EJECTION INJURIES /*NECK (ANATOMY) /*SPINE /*X RAY ANALYSIS / CONSCIOUSNESS / MOBILITY / NEUROLOGY / PATHOLOGY / POSITION (LOCATION) /

Quest Accession Number : 84A10748
84A10748 NASA IAA Conference Paper Issue: 01
The correlation and description of windflail injury mechanisms in the windblast environment
(AA)SMITH-LAGNESE, S. D.; (AB)KAZARIAN, L. E.
Author Affiliation: (AB)(USAF, Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH)
IN: SAFE Association, Annual Symposium, 20th, Las Vegas, NV, December 6-10, 1982, Proceedings (A84-10706 01-01). Van Nuys, CA, SAFE Association, 1983, p. 293-296., Publ. Date: 830000 Pages: 4 refs 9 Language: EN (English)
A biomechanical assessment is applied to classify extremity windblast injuries incurred during seat ejection from an aircraft in order to identify the causative factors for the injuries. Data from ejections from F-4 aircraft during 1967-1978 are examined, including airspeed, attitude, body position at ejection, type of injury, location, and reported causal factors. Attention was focused on fracture and fracture/dislocation injuries. A total of 40 aircraft containing 78 aircrew members were included in the study, which covered 50 sustained injuries. The type and extent of the trauma was found to be a function of airspeed, attitude, and initial body position. Radiographic techniques are recommended for delineating the causal factor that produced a particular injury pattern.
M.S.K.
Category code: 03 (air transportation/safety)
Controlled terms: *BIODYNAMICS /*BLAST LOADS /*EJECTION INJURIES /*F-4 AIRCRAFT /*FLIGHT CREWS /*WIND EFFECTS / AIRSPEED / ATTITUDE (INCLINATION) / MUSCULOSKELETAL SYSTEM /

Quest Accession Number : 83N19428
83N19428# NASA STAR Conference Paper Issue: 09
Injury mechanisms in frontal collisions involving glance-off
(AA)REIDELBACH, W.; (AB)ZEIDLER, F.
Corp. Source: Daimler-Benz A.G., Stuttgart (West Germany). (DA229785)
In AGARD Impact Injury Caused by Linear Acceleration: 4 p (SEE N83-19421 09-51). Publ. Date: 821000 Pages: 4 refs 0 Language: EN (English) Avail.: NTIS HC A21/MF A01
Among frontal car collisions offset impact collisions are three times more frequent than symmetrical ones. In case of small overlap and high collision speed the colliding vehicles glance-off. The definition and application of the energy equivalent speed helps to evaluate crash severity and to distinguish glance-off from non-glance-off collisions. The investigation of frequency and severity of injuries to belted occupants unveils that in case of glance-off, due to he impact-shock syndrome, the injury risk of lower extremities in increased, the injury risk of remaining body regions is reduced when compared to non-glance-off cases.
Author
Category code: 52 (aerospace medecine)
Controlled terms: *AUTOMOBILE ACCIDENTS /*COLLISION PARAMETERS /*CRASH INJURIES / IMPACT DAMAGE / RISK / SEAT BELTS /

Quest Accession Number : 83N19423
83N19423# NASA STAR Conference Paper Issue: 09
Mechanisms of head impact injury and modification by helmet protection
(AA)NAHUM, A. M.; (AB)WARD, C.
Author Affiliation: (AB)(Biodynamic/Engineering, Inc.)
Corp. Source: California Univ., San Diego. (CD305309) Medical Center.
In AGARD Impact Injury Caused by Linear Acceleration: 29 p (SEE N83-19421 09-51). Publ. Date: 821000 Pages: 29 refs 0 Language: EN (English) Avail.: NTIS HC A21/MF A01
Head protection provided by helmets or padding on the impacted cadaver skull surface was examined. Using unembalmed human cadaver subjects, frontal and lateral head impacts were conducted. Head acceleration and intracranial pressures were measured in order to determine the head and brain responses. Brain response was further analyzed with the aid of a finite element brain model; each impact was simulated on the computer to determine brain stresses and displacement during the impact. The degree of protection provided can be quantified by comparing head acceleration and brain pressures for equivalent energy impacts.
Author
Category code: 52 (aerospace medecine)
Controlled terms: *BRAIN /*HEAD (ANATOMY) /*HELMETS /*IMPACT TESTS /*INJURIES /*SKULL / COMPUTERIZED SIMULATION / FINITE ELEMENT METHOD / MATHEMATICAL MODELS /

Quest Accession Number : 83N19421
83N19421# NASA STAR Conference Proceedings Issue: 09
Impact Injury Caused by Linear Acceleration: Mechanisms, Prevention and Cost
(AA)HALEY, J. L., JR.
(AA)ed.
Author Affiliation: (AA)(Army Aeromedical Research Lab.)
Corp. Source: Advisory Group for Aerospace Research and Development, Neuilly-Sur-Seine (France). (AD455458)
AD-A123814; ISBN-92-835-0317-0; AGARD-CP-322 London, Publ. Date: 821000 Pages: 495 refs 0 Conf. held in Cologne, 26-29 Apr. 1982. Language: AA (Mixed) Avail.: NTIS HC A21/MF A01
Spinal column injuries under compressive, bending, and tensile loads; leg, head, and neck injuries; injury data collection; injury preventing hardware; seat/man models; and crashworthiness are addressed. For individual titles, see N83-19422 through N83-19454.
Category code: 51 (life sciences)
Controlled terms: *CONFERENCES /*CRASH INJURIES /*CRASHWORTHINESS /*HELICOPTERS /*IMPACT ACCELERATION /*IMPACT DAMAGE /*IMPACT TESTS /*INJURIES / AUTOMOBILE ACCIDENTS / DATA ACQUISITION / HARDWARE / HEAD (ANATOMY) / HUMAN FACTORS ENGINEERING / LEG (ANATOMY) / LOADS (FORCES) / NECK (ANATOMY) / SPINE /

Quest Accession Number : 82N22879
82N22879# NASA STAR Technical Report Issue: 13
Analysis of vertebral stress distributions and ejection-related injury mechanisms / Final Technical Report, 1 Jul. 1977 - Jan. 1980
(AA)PLESHA, M.; (AB)BELYTSCHKO, T.
Corp. Source: Northwestern Univ., Evanston, Ill. (N6683851) Dept. of Civil Engineering. AG749748
AD-A098639; AFAMRL-TR-80-67 Contract: F33615-77-C-0526 AFAMRL, Wright-Patterson AFB, Ohio, Publ. Date: 810200 Pages: 51 refs 0 Language: EN (English) Avail.: NTIS HC A04/MF A01
Stress analyses of lumbar vertebrae were performed by a three dimensional finite element method for the purposes of evaluating simplified models of the vertebrae which are suitable as injury postprocessors, and gaining a better understanding of injury mechanisms. The finite element analyses were linear and elastic. Axial and moment loads were applied over the end plates to simulate G(Z) impact and on the facets to simulate load transmission between the articular facets and the vertebral bodies. The finite element model predicts that the maximum stresses under axial load are perpendicular to the axis of the vertebral body, which are called axial stresses; this is consistent with the predominance of compressive and wedge fractures. However, the maximum stresses predicted by the finite element model are only about a third of those predicted by the simplified injury model. This discrepancy is due to the fact that a substantial portion of the total load is transmitted through the vertebral centrum which is neglected in the simplified model.
S.L.
Category code: 52 (aerospace medecine)
Controlled terms: *AXIAL LOADS /*EJECTION INJURIES /* MOMENT DISTRIBUTION /*STRESS CONCENTRATION /*TORSIONAL STRESS /*VERTEBRAE / BENDING MOMENTS / BIODYNAMICS / FINITE ELEMENT METHOD / MAXIMUM LIKELIHOOD ESTIMATES / PREDICTION ANALYSIS TECHNIQUES / SPINE /

Quest Accession Number : 82A11032
82A11032 NASA IAA Journal Article Issue: 01
Retro-hyperflexion luxation - Mechanism of cervical spinal cord contusion injury during ejection sequence
(AA)HAZZARD, R. C.
Author Affiliation: (AA)(U.S. Marine Corps Air Station, Yuma, AZ)
(Joint Committee on Aviation Pathology, Scientific Session, 12th, Aylesbury, Bucks., England, Oct. 14-16, 1980.) Aviation, Space, and Environmental Medicine, vol. 52, Oct. 1981, p. 625, 626., Publ. Date: 811000 Pages: 2 Language: EN (English)
Category code: 52 (aerospace medecine)
Controlled terms: *AEROSPACE MEDICINE /*AIRCRAFT PILOTS /* BACK INJURIES /*EJECTION INJURIES /*SPINAL CORD / MILITARY AVIATION / PARACHUTING INJURY /

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-LS-208	ISBN 92-836-1068-7	UNCLASSIFIED/ UNLIMITED

5. Originator Advisory Group for Aerospace Research and Development
North Atlantic Treaty Organization
7 rue Ancelle, 92200 Neuilly-sur-Seine, France

6. Title
Injury Prevention in Aircraft Crashes:
Investigative Techniques and Applications

7. Presented at/sponsored by
The Aerospace Medicine Panel and the Consultant and Exchange Programme of AGARD presented on 24-25 November 1997 in Farnborough, UK, and 1-2 December 1997 in Madrid, Spain.

8. Author(s)/Editor(s)	9. Date
Multiple	February 1998

10. Author's/Editor's Address	11. Pages
Multiple	100

12. Distribution Statement There are no restrictions on the distribution of this document. Information about the availability of this and other AGARD unclassified publications is given on the back cover.

13. Keywords/Descriptors

Aircraft accidents	Crash landing
Injuries	Survivability
Accident investigations	Crashworthiness
Acceleration tolerance	Aviation safety
Acceleration stresses (physiology)	Aerospace medicine

14. Abstract

This Lecture Series addresses a critical aspect of the investigations related to the factors implied in the prevention of potential injuries among aircraft occupants as a consequence of impact and post-crash fires, heat and toxic fumes. It comprises a review of the critical aspects of injury prevention.

The topics covered include a description of the acceleration vectors involved, how they may have an influence on the aircraft, and how the acceleration forces might be tolerated by the aviator. In addition, the physical analysis of impact and crash survivability is discussed, focusing on what happens during a mishap. Furthermore a review is made on how to evaluate the tolerable deceleration forces and occupiable space required to sustain life.

A part of this LS is devoted to answering questions such as, when did the injury occur, the nature of the forces that produced the injury, and their relationship to a mishap. Injury types related to the thermal and intrusive impact of the deceleration forces are also discussed, as are aspects related to the collection of medical information that would help identify the potential causes and the effects on an individual; in particular, the way in which the occupant moves in response to the forces applied. These forces may have a profound effect upon the nature and severity of the injury.

This Lecture Series, sponsored by the Aerospace Medicine Panel of AGARD, has been implemented by the Consultant and Exchange Programme.

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(membre de la Corporation St-Joseph)
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Printed by Canada Communication Group Inc.
(A St. Joseph Corporation Company)
45 Sacré-Cœur Blvd., Hull (Québec), Canada K1A 0S7

ISBN 92-836-1068-7